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Atlas of Immediate Dental Implant Loading

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Contents

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Part I

Biological Principles of Immediate Loading

Introduction to Immediate Loading in Implantology

Enrica Giammarinaro, David Soto-Peñaloza, Javier Aizcorbe-Vicente, Miguel Peñarrocha-Diago, Ugo Covani, and David Peñarrocha-Oltra

Abbreviations

CL	Conventional loading
DL	Delayed loading
EL	Early loading
IL	Immediate loading
INFL & IR	Immediate nonfunctional loading and immediate restoration
IR	Immediate restoration
ISQ	Implant stability quotient
IT	Insertion torque
OL/NOL	Occlusal loading or non-occlusal loading

Take-Home Message

In the last decades, a deeper understanding of bone biology and advance in implant technology allowed a significant evolution of surgical and prosthetic protocols. Early loading and immediate loading protocols have been introduced to reduce the total treatment time and to accommodate new patient needs.

The Evolution of Loading Protocols: Delayed, Early, and Immediate Loading

Brånemark traditional recommendation was to perform implant rehabilitation in two stages: the first entry was only for implant placement; after 3–6 months of undisturbed submerged healing for mandible and maxilla respectively (Adell et al. 1981; Albrektsson et al. 1986), a second surgical entry would have allowed loading of the implants (Randow et al. 1999; Gapski et al. 2003). The rationale behind this approach was that implant micro-movements as consequence by an inadequate primary stability, caused by functional forces at the bone-implant interface in the early wound healing stages, could have induced fibrous tissue formation rather than new bone (Brunski et al. 1979; Lioubavina-Hack et al. 2006), eventually causing clinical failure.

However, the discomfort, inconvenience, and anxiety associated with the waiting period remained a challenge to the patients. The main request was to reduce the overall rehabilitation time from surgery to final restoration delivery: installation of implants in fresh extraction sockets and immediate restored implants have been adopted.

First reports on immediate loading of dental implants can be traced back to the early 1960s thanks to the contribution of Dr. Leonard Linkow. He described immediate loading protocols for root-form and blade implants (Linkow and Mahler 1977). In 1979, Philippe D. Ledermann advised the placement of four non-submerged intra-foramina mandibular implants, in areas where the bone was at least 11 mm in height, and suggested to immediately load them with a splinting bar-retained restoration (Ledermann 1979). This protocol showed favorable long-term clinical results for totally edentulous mandibles, and the reported success rate after a functional phase of 1–72 months was 92.34% for 415 implants on 122 patients. In a later publication, the author summarized 20 years of experience reporting data for 523 implants on 411 patients with an average permanence time of 7.23 years. The survival rate was fair, standing at 92% (Ledermann 1996).

Schnitman and colleagues discussed the possibility of using an immediate fixed partial prosthesis without compromising long-term implant survival in the edentulous mandible (Schnitman et al. 1990).

The authors placed five to six implants in the anterior mandible and two implants distal to the foramina. Abutments

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were connected immediately after surgery to the two distal fixtures and to one fixture in the anterior region. A provisional immediate fixed restoration was loaded on the three exposed implants, whereas the remnant submerged implants served as control. The authors showed that the overall implant success was not affected by the loading procedure.

Nevertheless, at that time, the variation of reported implant survival rates and time of actual loading was high among different clinical studies. Brånemark suggested that the possible reason for high discordance regarding immediate loading was amenable to the lack of consensus on the optimal way to do it. He presented the "same-day-teeth" concept for treatment time reduction in the edentulous mandible, using a standardized methodology involving a rigid connection of the implants at the time of implant surgery with prefabricated prosthetic components. The author reported a success rate of 98% following a functional phase of 6–36 months (Brånemark et al. 1999). In general, the early beginning of immediate loading was a cautious and exploratory period in which authors tended to limit this procedure to areas characterized by dense, high-quality bone.

Since the former reports of immediate loading (Linkow and Mahler 1977; Ledermann 1979), further improvements and innovations in terminology were described to enhance the understanding of this topic. The first immediate loading consensus statement from the Spanish Society of Implantology (SEI) reported by Aparicio et al. (2003) marks a milestone, as attempt to standardize immediate loading definition, and it would become a start point for the evolution of immediate loading terminology across different task forces of international societies of oral implantology and research teams, through clinical studies, reviews, and consensus statements (Degidi and Piatelli 2003; Cochran et al. 2004; Nkenke and Fenner 2006; Esposito et al. 2007; Weber et al. 2009; Gallucci et al. 2014). A timeline for immediate loading concepts evolution is depicted in Fig. 1.

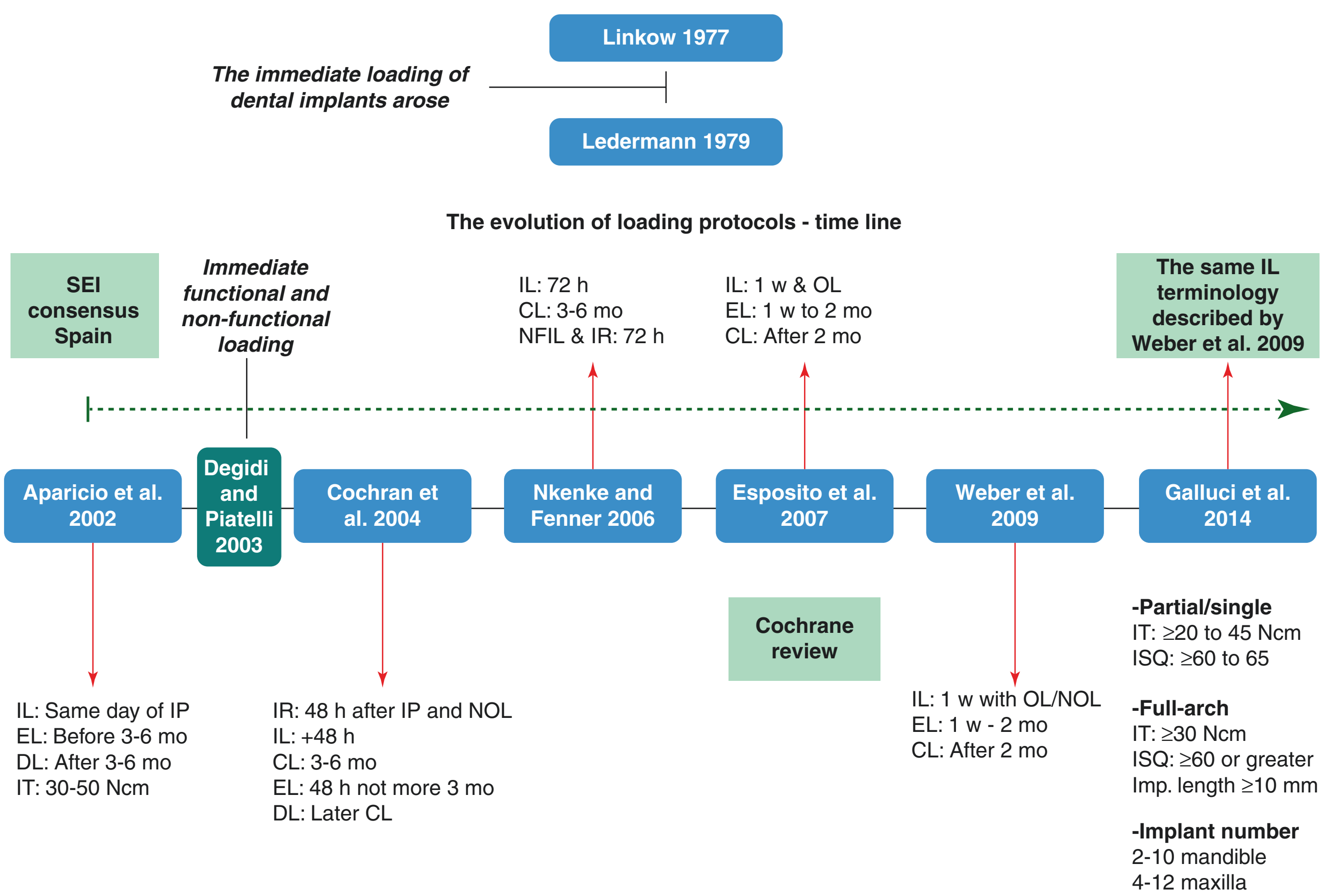


Fig. 1 Evolution of the terminology of immediate loading. Abbreviatures: Immediate restoration (IR): not in occlusion with opposite dentition. Immediate loading (IL): a restoration placed in occlusion with opposite dentition. Early loading (EL): a restoration placed in occlusion with opposite dentition, in a time period range. Conventional loading (CL): prosthesis is attached in a second procedure after a healing period. Delayed loading (DL): takes place some time later than the conventional healing. Immediate nonfunctional loading and immediate restoration (INFL and IR): provisional prostheses are not in occlusion, serve only for esthetic and soft tissue purposes. Occlusal loading or non-occlusal loading (OL/NOL): insertion torque (IT), implant stability quotient (ISQ), implant placement (IP), months (mo), week (w)

Implants with Immediate Loading

Immediate loaded implants (occlusal or non-occlusal loading) are those subjected to prosthetic functionalization within a week of implant placement; updated implant loading terminology is depicted in Table 1. Immediate loading implies that implants would be exposed to the oral environment and subjected to functional loads; therefore some biologic assumptions should be considered:

- Osseointegration would not be affected because of oral exposure of the implant surface.
- Osseointegration would not be affected because of immediate loading.
- Ideal healing time would be very sacrificed.

Even further, we might say that functional forces are key triggers to a series of biological reactions that not only accelerate the initial healing process but also the structural changes of peri-implant bone.

Those assumptions have been supported by several preclinical and clinical studies. The idea is that well-planned loading forces transmitted to the implant might even enhance bone healing in the early stages with more favorable long-term bone and soft tissue outcomes (Romanos 2015). The pioneering experiments by Schroeder and colleagues showed that the physicochemical bone-implant bond is strengthened by functional loading (Schroeder et al. 1978). The fresh bone accumulates on the rough surface and probably propagates as a result of the forces transferred directly to the bone. Further clinical examinations were carried out to transfer this concept to daily clinical practice. Clinical examinations using immediate loading protocol in the posterior mandible showed similar clinical and radiological results for the implants when compared to delayed loading. That means that implants can be immediately loaded also in areas with a relatively weak quality of bone if some important requirements are taken into account. Optimum initial implant stability in low-density bone is a prerequisite for long-term success. Adequate initial splinting improves the prognosis, especially where the bone is of inadequate quality. Critical evaluation of the literature shows that a non-loaded healing period is no longer essential.

Table 1 Actual ITI accepted immediate loading terminology

Terminology of loading protocols	
Immediate loading	Prosthesis connected to the dental implant within 1 week subsequent to implant placement with occlusal loading or non-occlusal loading
Early loading	Prosthesis connected to the dental implant between 1 week and 2 months subsequent to implant placement
Conventional loading	Prosthesis connected to the dental implant more than 2 months subsequent to implant placement

Justification for Immediate Loading

According to standard protocols of implantology, implants should be load-free during the osseointegration period (3–4 months in the jaw and 6–8 months in the maxilla) to prevent formation of a fibrous scar tissue between bone and implant and to achieve a predictable high success (Albrektsson et al. 1981). This standard protocol for restoration of the completely edentulous jaw with implant-supported full-arch prosthesis has been seen to produce favorable results (Peñarrocha-Oltra et al. 2014b).

When only posterior teeth are involved, patients do not usually complain about this time-lengthy approach; however they are unwilling to wait so much time when they are missing all the teeth in one of the arch or when they have lost teeth in the esthetic zone (Crespi et al. 2007; Peñarrocha-Oltra et al. 2014b; Tarazona et al. 2014; Barone et al. 2016). In the case of total edentulism, the dental clinician should respond effectively to the social and psychological needs of patients, providing them with provisional prosthesis during the osseointegration period. However, many patients complain about the discomfort of these temporary prostheses which are barely functional to their perspective (Testori et al. 2003). If only one tooth or a few teeth are missing, they can be replaced with a removable prosthesis stabilized by clasps. Sometimes patients cannot tolerate a removable partial denture so the clinician can make provisional fixed partial dentures bonded to the adjacent teeth, but these prostheses have to be removed during crown preparation and then rebounded again. These provisional restorations also have poor esthetic and are barely functional; furthermore the management of the cervical portion should be trimmed carefully around the mucosa to prevent the impairment of soft tissue healing.

The growing esthetic and functional demands from patients have favored the development of alternative surgical techniques to shorten the period from the placement of implants to the prosthetic loading. Immediate loading protocol allows patients to wear their implant-supported prostheses before the first week after implant surgery, avoiding a secondary surgery (Testori et al. 2003; Sanz-Sanchez et al. 2015; Esposito et al. 2013; Yan et al. 2016).

Immediate Loading in Different Scenarios

In the following section, an overview of immediate implants survival rates in different scenarios is presented (Table 2).

Post-extractive and Immediately Loaded Dental Implants

The idea of immediate and early loading on post-extractive implants has been introduced to further improve patients'

Table 2 Summary of literature-reported survival rates for immediate loading in different clinical situations

Immediate loading protocols	Implant survival (%)	Reference
Post-extractive implants	96	Del Fabbro et al. (2015)
Full-arch rehabilitations		Peñarrocha-Oltra (2013)
– Maxilla	96	
– Mandible	98.2	
Zygomatic implants	95.8–100	Wang et al. (2015)
All-on-four	97.6–100	Soto-Penaloza et al. (2017)
Single implants		Yan et al. (2016)
– Anterior	98.25	
– Posterior	91.7–100	

quality of life and to accomplish a simplified therapeutic protocol (Barone et al. 2006). Immediate post-extractive implant placement and loading shorten the healing period, reduce the number of surgical sessions, minimize patient's morbidity and discomfort, limit post-extraction socket remodeling, and allow the clinician to shape and condition the peri-implant soft tissue level. Nevertheless, this procedure is advanced and might be tricky when the residual bone is thin and the gap between the implant and the residual bone is wide.

The implant osteotomy bed and the extraction sites differ in their geometry; therefore, the healing processes of delayed implants and post-extractive ones are not superimposable. In particular, the early phase of repair takes less time in a fresh extractions socket (Wang et al. 2017; Li et al. 2017; Pei et al. 2017), and this peculiarity is probably related to two factors: (1) the peri-implant environment of the post-extractive site contains periodontal ligament remnants which promotes faster healing, and (2) the presence of an irregular bone-to-implant contact decreases the strain stress along the post-extractive implant (Yuan et al. 2018). Those histological findings support the idea of a more favorable environment for wound healing in post-extractive sites undergoing immediate loading than in healed sites undergoing implant bed preparation through drilling.

The 7-year clinical study by Barone and colleagues reported an overall success rate of 94.6% for implants placed in extraction sockets and immediately restored (Barone et al. 2016). The authors suggested that implants placed immediately after tooth extraction and immediately restored had favorable clinical outcomes and stable tissues conditions at a long-term evaluation.

The 2015 meta-analysis by Del Fabbro and co-workers showed better survival rates for implants placed in healed ridge (IS = 99.4%) as compared with post-extraction implants (IS = 95.6%). Yet, immediate restoration of implants placed in fresh extraction sites displayed an excellent implant prognosis. Therefore, such clinical approach can be safely adopted, minimizing the total treatment time and increasing patient's satisfaction (Del Fabbro et al. 2015). In 2017 Zhang published the results of a meta-analysis investigating the non-inferiority of immediate loading in clinical and radiographic outcomes compared with non-immediate loadings (Zhang et al. 2017). They found no differences in implant survival rates nor in marginal bone loss. The non-inferiority of immediate loading was demonstrated both at implant and patient levels.

A post-extractive immediate loading sequential case is depicted in Fig. 2a–s.

Immediate Loading with Full-Arch Prosthesis

The 2007 systematic review by Thomason and co-workers pointed out that the rehabilitation of total edentulism leads to significant improvements in patient quality of life (Thomason et al. 2007). Furthermore, patients restored with implant-retained prosthesis reported greater satisfaction than that of patients restored with conventional removable dentures. Loading protocols for implant-retained prosthesis in the edentulous jaws have been discussed in terms of clinical efficacy. Immediate loading has been introduced to reduce treatment time and to increase patient quality of life with a faster return to oral function. Immediate loading in the fully edentulous jaw by means of a fixed prosthesis is a well-documented treatment concept.

The 2014 systematic review by Papaspyridakos and colleagues revealed that the loading protocol had no influence on the prosthodontic survival rates of implant-retained full-arches in the mandible (Papaspyridakos et al. 2014). Niedermaier followed a cohort of 380 patients treated with implant-supported immediately loaded fixed full-arch dentures for 7 years, and the implant survival rate was 96% in the maxilla and 98.2% in the mandible (Niedermaier et al. 2017). Osteoporotic and smoking patients at a significant level recorded lower scores.

Immediate loading protocols for the maxilla are often regarded with extreme caution due to different bone quality, which is more trabecular, compared to the mandible. However, survival rates between mandible and maxillae did not yield significant differences. The reported survival rate for immediately loaded implants with fixed full-arch prosthesis in the maxilla ranges from 87.5% to 99.2%, with great heterogeneity among different studies (Peñarrocha-Oltra et al. 2014a). No differences could be observed in terms of marginal bone resorption between immediate and conventional loading. In general, immediate loading with full-arch

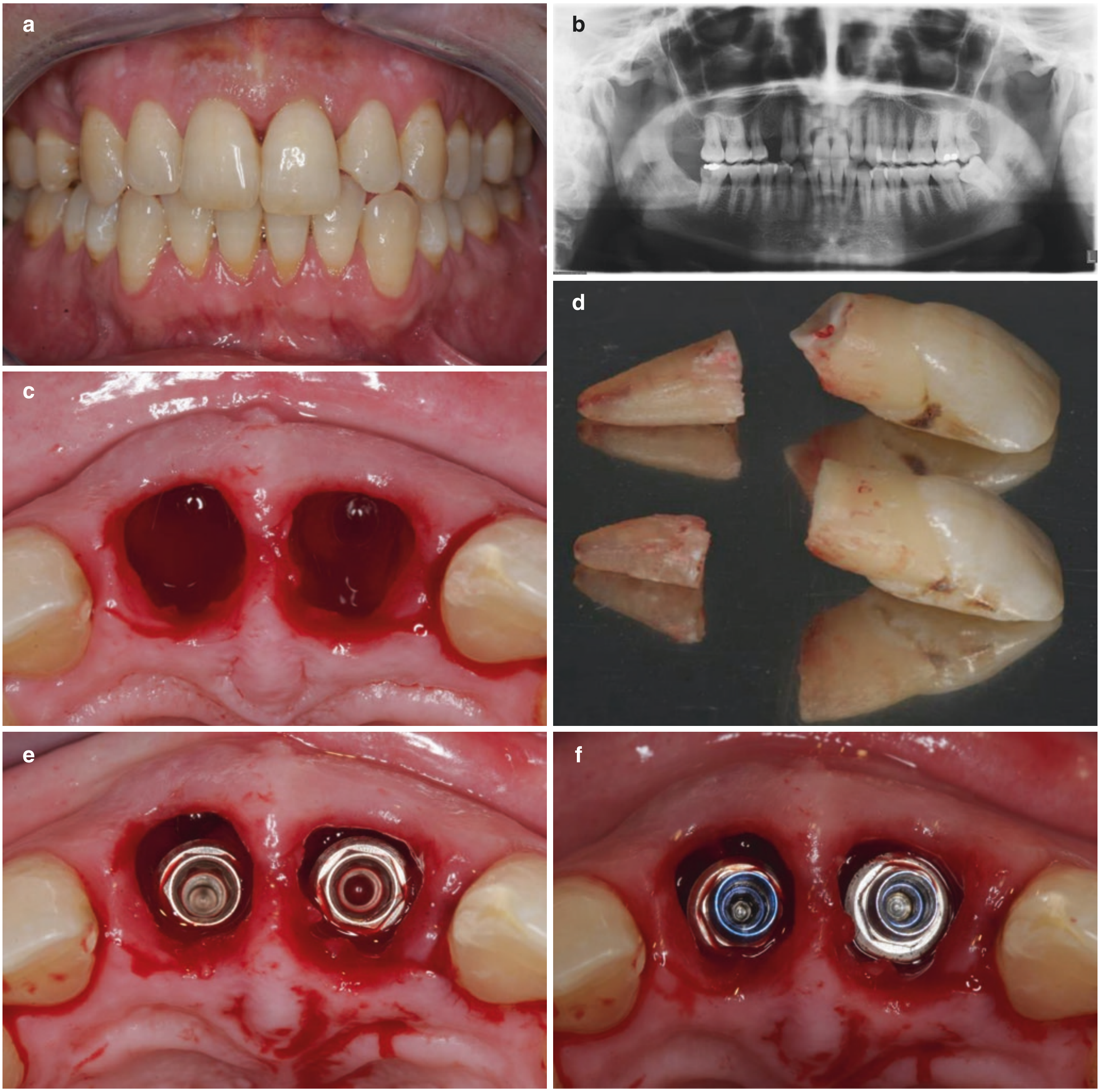


Fig. 2 (**a**) Coronal portion mobility at central incisors is appreciated at clinical exploration. (**b**) A horizontal radicular fracture of 1.1 and 2.1 is observed in the panoramic X-ray. (**c**) Atraumatic teeth extraction. (**d**) View of fractured teeth after extraction. (**e**) Occlusal view of implants within extraction socket (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**f**) Prosthetic abutments positioned and screwed on implant connection. (**g**) Insertion of temporary abutments. (**h**) Lab work screw placement. (**i**) After perforation of the temporary prosthesis, it was tried to check any interferences during insertion. (**j**) Auto-polymerizable resin was placed within temporary prosthesis for stabilize. (**k**) Contouring and polishing of the provisional restoration. (**l**) Prosthesis screwing and placement of temporary obturation material. (**m**) Frontal view after immediate repositioning of provisional restoration and surgical suture. (**n**) Suture removing after a postoperative week. (**o**) After osseointegration process, a definitive prosthesis was confectioned; it was observed that a good soft tissue contouring is appreciated. (**p**) Frontal view of soft tissue architecture. An adequate keratinized tissue band is appreciated. (**q**) To attain a good esthetic in anterior zone, a zirconium material prosthesis was done. (**r**) Clinical view of final restoration. (**s**) Final panoramic radiograph

Fig. 2 (continued)

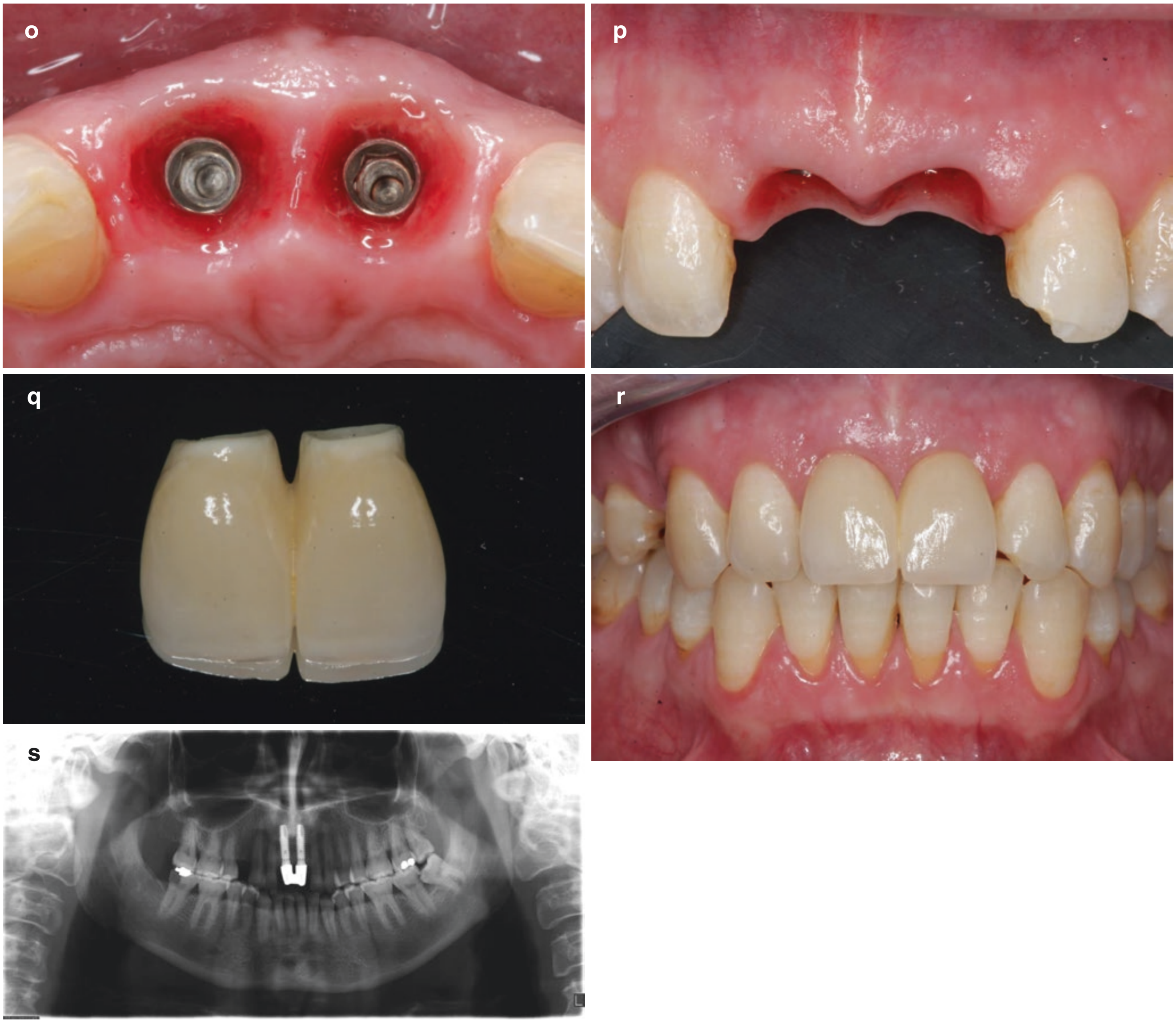


Fig. 2 (continued)

prostheses in the maxilla is a successful and predictable procedure if adequate criteria are met during patient selection, surgery, and prosthetic delivery with benefits on patient-reported outcomes than conventional loading (Peñarrocha-Oltra et al. 2014b). The most reported complication is limited to the fracture of the provisional prosthesis, and this outcome is often related to preexistent bruxism (Cercadillo-Ibarguren et al. 2017).

In 2014, De Bruyn summarized the evidence regarding immediate loading in completely edentulous jaws (De Bruyn et al. 2014). When four or more implants are placed, the implant failure is 0–3.3% in the mandible. In the maxilla, four to six implants yield a failure rate of up to 7.2%, but this is reduced to 3.3% when the number of implants is increased. An immediate loading full-arch reconstruction is depicted in Fig. 3a–y.

Immediate Loading and Zygomatic Implants

Available bone volume for implant placement is frequently limited in the atrophic maxilla because of post-extraction alveolar bone resorption and pneumatization of the maxillary sinus. Several bone grafting techniques, such as sinus lifting and bone grafting procedures, have been described as methods to restore the volume of the atrophic maxillae, allowing implant placement in reabsorbed sites (Esposito et al. 2014). However, those procedures require additional surgery and increased morbidity for the patient, demanding considerable time until final prostheses can be delivered.

A less invasive alternative to major reconstruction procedures for the severe atrophic maxilla is the zygomatic implant. Prostheses supported by four zygomatic implants or two zygomatic implants combined with two standard anterior implants were successfully introduced and successfully approached in restoring function in the severely atrophic maxilla.

A review of the literature on 1541 zygoma implants reported a survival rate of 97.8% (Goiato et al. 2014). The authors also reported that most studies that have investigated zygomatic implants with immediate loading have used modified implant surfaces to achieve the primary stability.

Wang and colleagues performed a systematic review on the reliability of four zygomatic implant-supported prostheses reporting high survival rates for immediate loading protocols ranging from 95.8% to 100% (Wang et al. 2015).

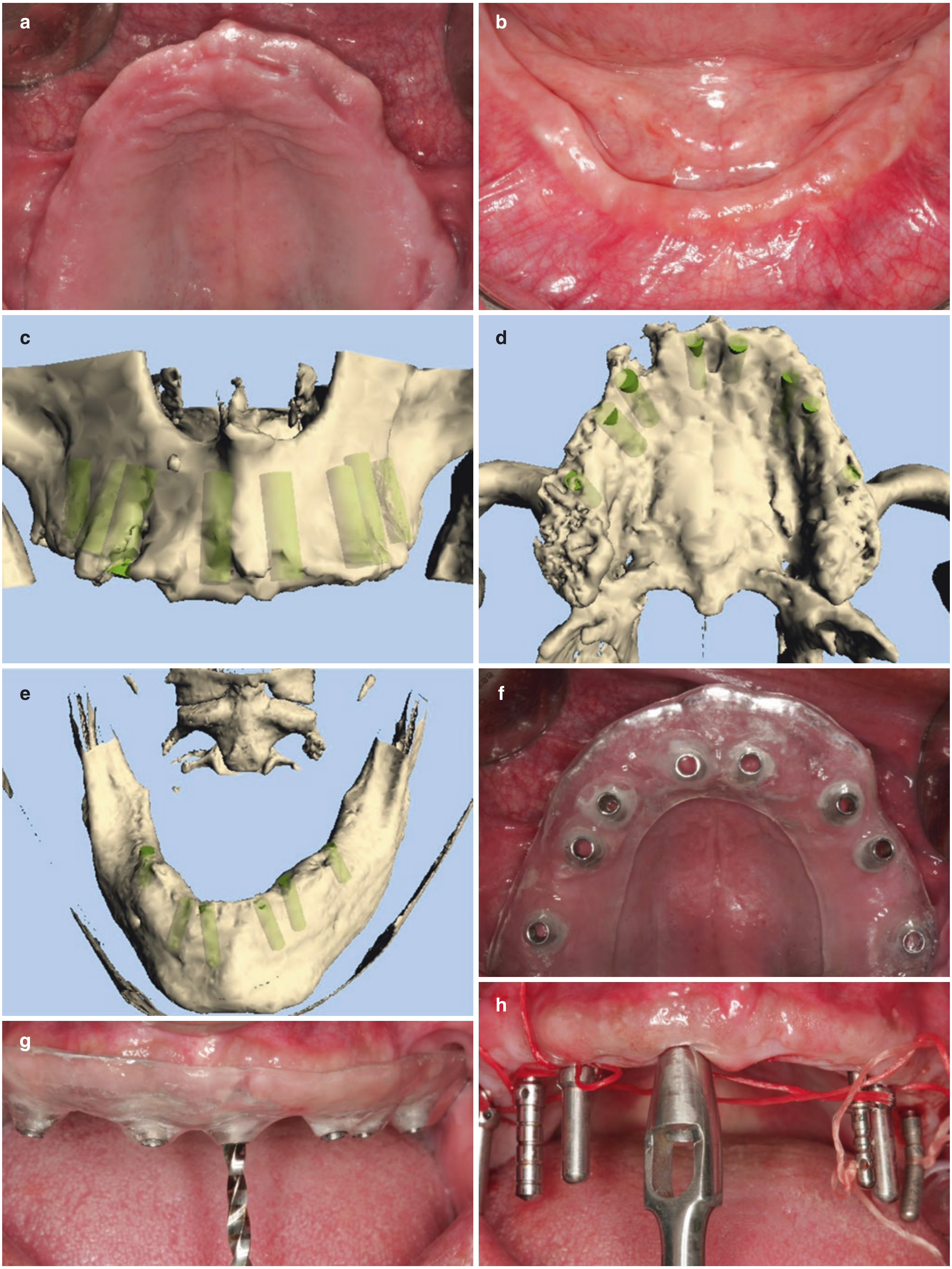
In 2017, Agliardi reported the 6-year outcome of full-arch maxillary prostheses retained by four zygomatic implants or two zygomatic implants in conjunction with two conventional fixtures. Implant survival was 100% with high level of patient satisfaction for function, esthetics, and phonetics (Agliardi et al. 2017). An important drawback of this approach is its advanced technical requirements; to ensure treatment success, a careful pre-operatory diagnosis should be performed on computed tomography scans.

Immediate Loading and the All-on-Four Treatment Concept

Long-term edentulous jaws often prevent implant placement. A noninvasive option to rehabilitate the atrophic jaws is the use of fewer implants placed with a polygon disposition. The all-on-four concept was introduced in 2003 and basically refers to the placement of two axially loaded anterior implants and two tilted implants in the posterior zone (Maló et al. 2003). The tilting of distal implants should allow for a reduction in the prosthetic cantilever length, resulting in decreased peri-implant bone stress (Horita et al. 2017).

Long-term data on fixed prostheses retained by four implants in the edentulous mandible showed similar outcomes of those retained by more implants (Gallucci et al. 2009). The recent systematic review by Soto-Penaloza and co-workers shed light upon the therapeutic indications, surgical procedures, prosthetic protocols, patient satisfaction, and main complications associated with the all-on-four treatment concept (Soto-Penaloza et al. 2017). The authors reported a success rate ranging between 94.8% and 100% at implant level; the survival rate ranged between 97.6% and 100%. Achieving adequate primary stability seems to be the most important factor in determining implant survival during the first year of loading. Implant primary stability has been often related to insertion torque, which is defined as the rotational resistance at the time of implant placement (Anitua

Fig. 3 (**a**) Intraoral clinical picture, maxillary occlusal view. (**b**) Intraoral clinical picture, mandible occlusal view. (**c**) 3D surgical planification software Implametric®. Frontal view of implant positioning in upper jaw. Data was send to dental lab for surgical splint confection with metallic guides, considering planed positions. (**d**) 3D surgical planification software Implametric®. Implant positioning was planned at the level of incisives, canines, first premolars, and molars. (**e**) 3D surgical planification software Implametric®. Aimed by computed tomography and dental software, six implants placement was planned in the lower jaw. (**f**) Maxillary surgical split was placed and its stability was checked. (**g**) Through the metallic guides in surgical splint, implant position was marked. (**h**) A soft tissue rib was removed with a surgical punch, then the implant bed was prepared, and implant parallelism was verified using surgical pins for this purpose. (**i**) Intraoperative occlusal view after implant placement (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**j**) Intraoperative occlusal view after implant placement. Transmucosal prosthetic abutments were placed to perform an immediate loading. (**k**) Intraoperative occlusal view after implant placement. Provisional caps were adapted; only the six anterior implants were used for the immediate loading. (**l**) Intraoperative occlusal view after implant placement. A duplicate provisional prosthesis of white resin was perforated to make holes at each implant position. It is obtained from the complete denture of patient. (**m**) Intraoperative frontal view of lower jaw. The surgical splint is placed to check its stability as in the upper jaw, and the implantation sites were marked. (**n**) Intraoperative view of lower jaw. A total thickness flap with distal discharges is raised. (**o**) Intraoperative view of lower jaw. Preparation of implant beds and parallelism verification using surgical pins for this purpose. (**p**) Intraoperative view of lower jaw. Placement of four implants of standard diameter in inter-foramina position and two distal implants of wide diameter (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**q**) Intraoperative view of lower jaw. After implant placement the implant transporters were removed. (**r**) Intraoperative view of lower jaw after implant placement. Transmucosal prosthetic abutments were placed to perform an immediate loading. (**s**) Intraoperative view of lower jaw after implant placement. After plastic cap placement, the flap was sutured. (**t**) Intraoperative view of lower jaw after implant placement. A gum dam is placed to avoid resin invagination during provisional restoration fixation. (**u**) Provisional restoration with four holes drilled. The prosthesis fitting was checked intraorally to avoid interferences with plastic caps. (**v**) Provisional prosthesis before final polishing and before the relining of retentive spaces to avoid biofilm accumulation. (**w**) Provisional prosthesis installation. After polishing of retentive borders and resin emergence contouring, the prostheses were adjusted using clinical short screws, according to manufacturer recommendations based on the screws metric. (**x**) Frontal view of installed prostheses in both maxillae. (**y**) Panoramic radiograph after implants placement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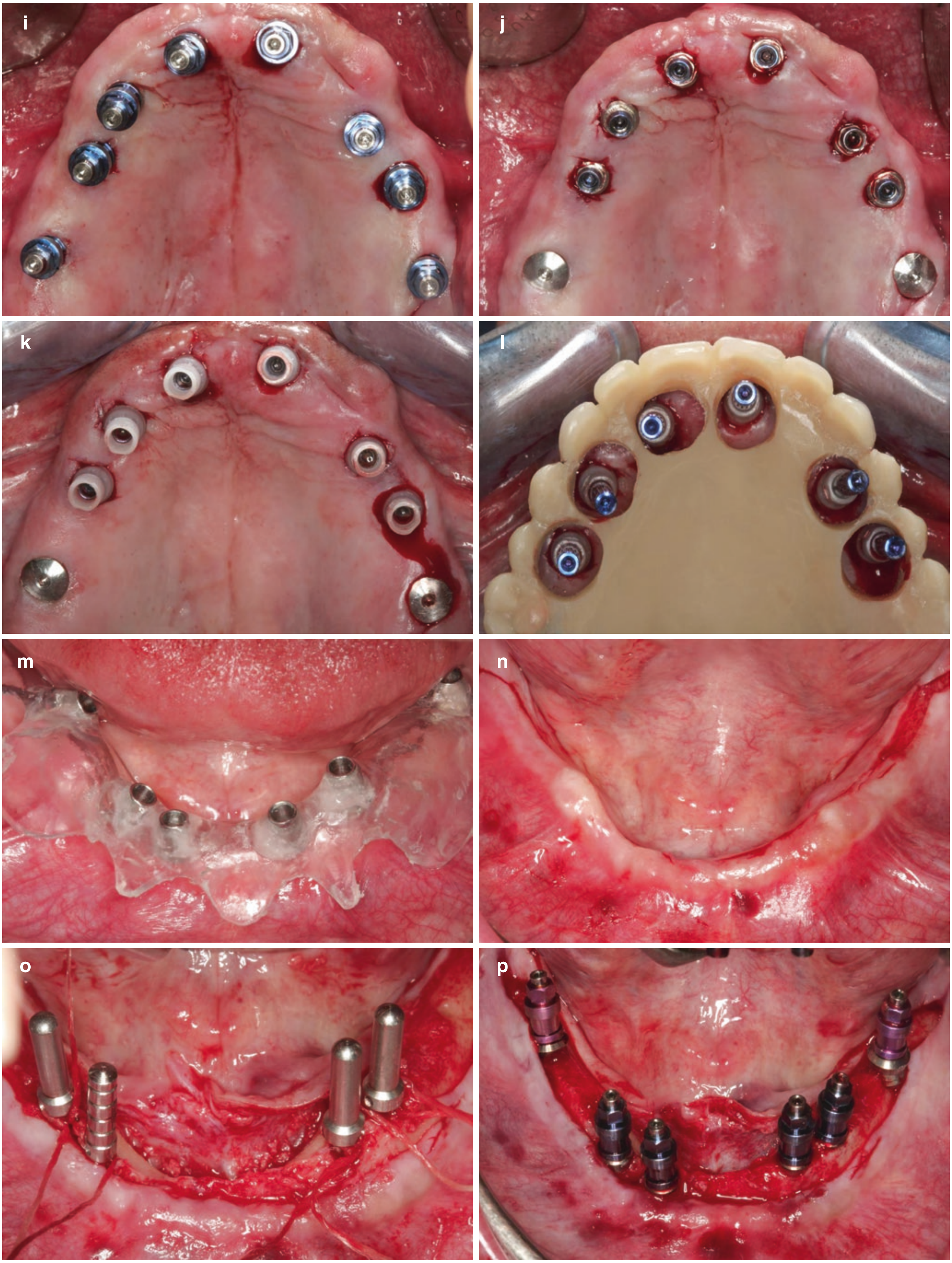

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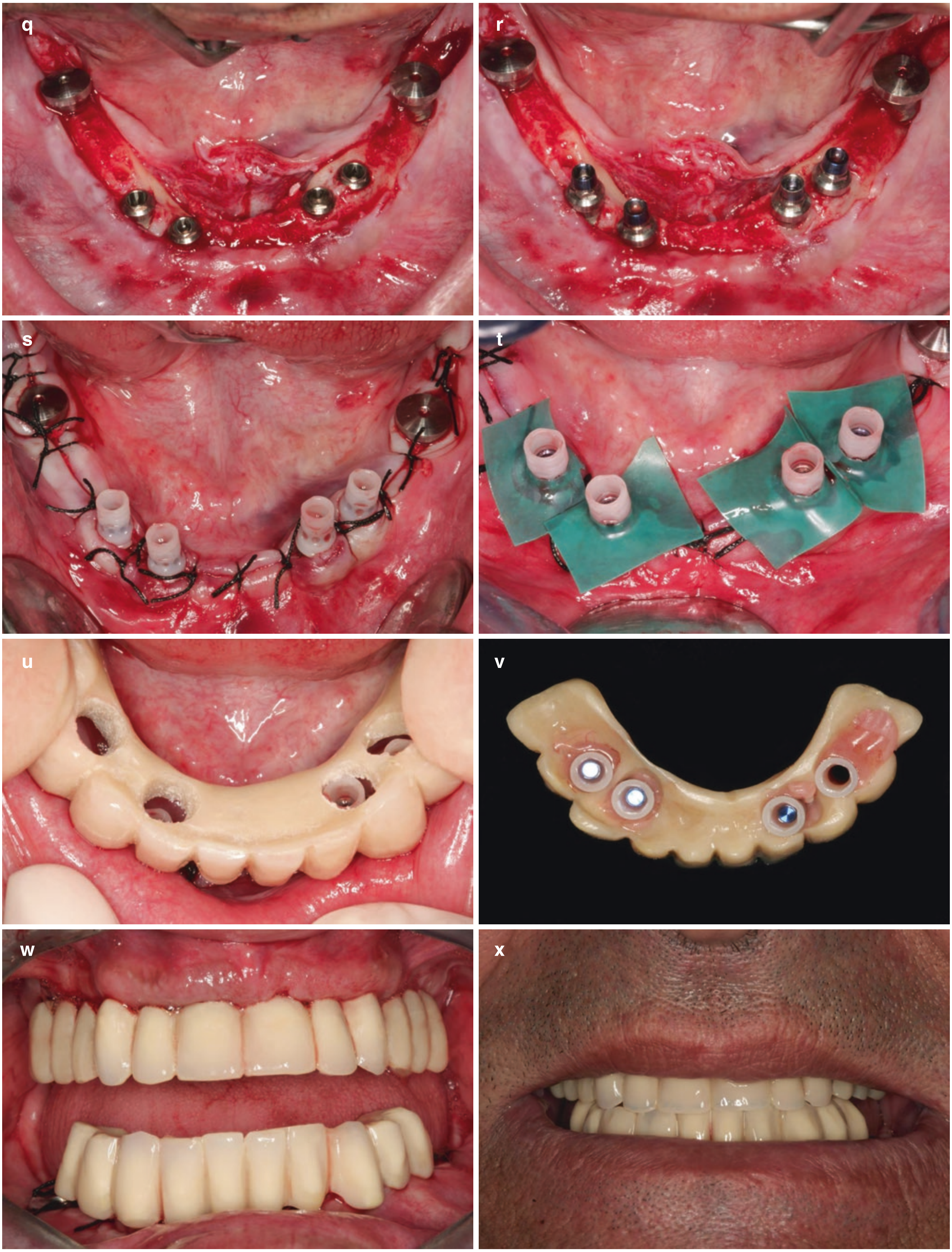

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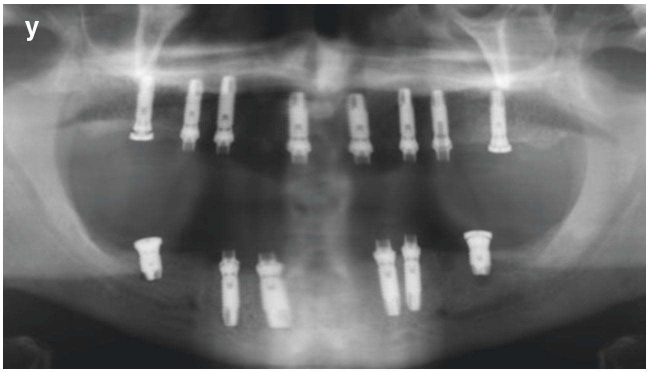

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et al. 2015). Even though it may seem intuitive that high insertion torque leads to better thread engagement to the bone, different preclinical and clinical studies have suggested that IT does not necessarily relate with primary stability (Marconcini et al. 2018). High levels of insertion torque might exceed the elastic limit of the bone causing compression necrosis and increasing the risk for marginal bone remodeling. Therefore, clinicians should pay great attention to insertion torque values when performing implant sites preparation for all-on-four implant-retained prostheses.

Immediately Loaded Single Implants

In 2016, Yan published a systematic review aiming to compare immediate protocols with conventional protocols of single-tooth implants in terms of changes in the surrounding hard and soft tissue in the esthetic area (Yan et al. 2016). The authors failed to prove any significant difference in marginal bone loss and soft tissue appearance—in terms of papillae filling—between immediate and delayed protocols in the anterior maxilla. Similar results have been suggested by Weigl and Strangio in 2016: immediate loading resulted in a high success (97.96%) and survival rate (98.25%) after a mean follow-up period of 31.2 months (Weigl and Strangio 2016).

The mean crestal bone and the mean interproximal mucosa level changes were less than 1 mm compared to the baseline. The midfacial peri-implant mucosal level change was less than 0.95 mm. A few potential risk factors for mucosal recession such as preexisting buccal bone defects, thin buccal bone, thin soft tissue biotype, and implant malposition have been identified. Accordingly, different authors have proposed treatment strategies to counteract the possible tissue changes, including the use of autologous connective tissue graft, xenograft fillers in peri-implant gap, and flapless surgery (Barone et al. 2016).

Moraschini and Barboza performed a meta-analysis to compare midterm implant survival, marginal bone loss, and complications between immediate and conventional loading of single implants installed in the posterior mandible (Moraschini and Porto Barboza 2016). They found no differences in terms of implant survival and marginal bone loss. The survival of the implants in the immediate and conventional loading groups at a mean follow-up of 31.2 months ranged from 91.7%13 to 100% and from 96.6% to 100%, respectively. Immediate loading in single implants could be with or without occlusal contact. A recent systematic review suggested that there are no clear impacts of occlusal contact on implant survival rates, which ranged between 85.7% and 100% (De Bruyn et al. 2014).

Concluding Remarks and Future Trends

The 2018 systematic review by Troiano and co-workers reported data from 11 trials included in the analytic comparison between two-stage and one-stage implants (Troiano et al. 2018). No differences were found in late implant failure nor in marginal bone loss. However, immediate loading was burdened by a higher risk for early failure (within 1 year). It must be said that adherence to scientific indications and guidelines alone is not sufficient to achieve implant success. An expert surgeon, a throughout anamnesis, a proper diagnosis, and an efficient communication with the patient would be crucial in the algorithm for immediate loading success. This consideration is all the more so in the case of early implant failure, which is often related to prosthetic planning mistakes or clinician inexperience.

Current trends in implant dentistry are shifting toward the digital workflow helped by evolving technologies. Reducing the need of grafting procedures and allowing for prosthodontically driven implant placement in the extremely atrophic jaws may be accomplished with the application of digital and CAD-CAM technology. The aim is to reduce the total chair time and the costs of implant therapy for both the patient and the clinician. The digital approach in immediate loading in the anterior area might help in achieving optimal esthetic results and facial integration of the implant-retained prosthesis. It must be remarked that guided surgery and digital planning require a significant learning curve.

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Basic Bone Biology Healing During Osseointegration of Titanium Dental Implants

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Abbreviations

3 integrin	Alpha (v) beta (3) integrin
BIC	Bone-to-implant contact
BMP	Bone morphogenetic protein
BMU	Basic multicellular unit
CaP	Calcium phosphate
DC-Stamp	Dendrocyte-expressed seven transmembrane protein
FGF	Fibroblastic growth factor
GLAST	Glutamate transport by transporters
HA	Hydroxyapatite
HVC	Haversian canal
IGF	Insulin growth factor
LB	Lamellar bone
LL	Lamellae
M-CSF	Macrophage colony-stimulating factor
NFATc1	Nuclear factor of activated T cells 1
OBM	Organic bone matrix
OSCAR	Osteoclast-associated, immunoglobulin-like receptor
PGE2	Prostaglandin-E2
PGI2	Prostacyclin
RANKL	Receptor activator of nuclear factor kappa-B ligand
SLA	Sandblasted/acid etched
Src	Proto-oncogene tyrosine-protein kinase
TGF-B	Transforming growth factor beta
WB	Woven bone

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Take Home Message

- The majority of bones of the skull, including jaws, form directly from mesenchymal cells from the first branchial arch without the prior formation of cartilage; this type of osteogenesis is called intramembranous ossification. It has three major cell types (osteocytes, osteoblasts, and osteoclasts) responsible for mechano-transduction, bone matrix secretion, and bone resorption, respectively.
- Woven bone (WB) is non-lamellar and characterized by the random disposition of type I collagen fibers and is the first type of bone tissue to appear in embryonic development and fracture repair. It is usually temporary and is replaced by lamellar bone.
- Lamellar bone (LB), characterized by multiple layers of calcified matrix containing osteons, which are bone functional units or the "Haversian system", refers to the complex of concentric lamellae, with one osteocyte interconnected by canaliculi containing the cells' dendritic process, connected with the processes of neighboring cells through gap junctions.
- Osteointegration is a dynamic process during the establishment and maintenance of implants, characterized by resorption and apposition events, and the extent and degree of osteointegration is in part affected by implant surface configuration and a number of variables (e.g., implant macro-design, surface treatment design, native bone features, timing of placement, and loading characteristics).
- It was recognized and suggested that the early osseointegration in an animal model was twice as effective as in humans.

Introduction

In 1892, Julius Wolff postulated that bone was a dynamic tissue that adapts to meet the physical demands of its external environment (Wolff 1986). Nowadays, bone is considered a

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dynamic, vascular, living tissue that changes throughout life and is one of the so-called "connective tissues" of the body and thus comprises cells that become embedded in their own extracellular matrix (Davies 2003).

Bone Response to Dental Implants

Dental implants can be integrated at both hard and soft tissue levels. The term osseointegration is related to the long-lasting and functional connection between a titanium fixture surface and surrounding bone at the implant bed, and it is developed across weeks of healing, with or without functional loading. Direct bone-to-implant contact (i.e., osseointegration) was first described by the Swedish scientist Per-Ingvar Brånemark and his coworkers (Adell et al. 1970; Southam and Selwyn 1970), and it was first histologically demonstrated by the Swiss scientist Andre Schroeder and his coworkers as 'functional ankylosis' (Schroeder et al. 1976, 1978, 1981); his group being the first to document direct bone-to-implant contact (BIC) for titanium implants in non-decalcified histologic sections.

This intimate relation of the implants surface and bone may be in part due to an interaction between titanium oxide–bone via proteoglycans (Listgarten et al. 1992). In the following years, further development of animal studies showed that various materials and surface configurations become osseointegrated (Schenk and Buser 1998; Salvi and Lang 2001). After years of constant research, efforts reflect significant findings, such as how the rough-surfaced implants possess a higher bone-to-implant contact and favor biomechanical stability (Berglundh et al. 2003; Abrahamsson et al. 2004; Shalabi et al. 2006; Le Guéhennec et al. 2007). Thus, aiming to enhance the understanding of processes implied during bone healing after dental implants placement, this chapter consists of a comprehensive review of the most relevant literature to develop the rationale of basic bone biology and key insights of the sequential healing of titanium dental implants in bone tissue.

Basic Aspects of Bone Biology and Architecture

The skeletal system develops from mesenchyme originated from the mesodermal germ layer and neural crest. Bone formation takes place in two ways. In most bones, including axial (vertebral column and ribs) and appendicular (limbs) skeletons, a cartilage model first forms and is finally replaced with bone, which is called endochondral ossification. In contrast, most flat bones, such as the majority of bones of the skull, form directly from mesenchymal cells from the first branchial arch without the prior formation of cartilage; this type of osteogenesis is called intramembranous ossification (Maruyama 2011).

Bone is a specialized connective tissue that offers support and mechanical stability to the skeleton. This tissue allows the body proper load bearing and locomotion, the latter through a system of levers that multiply the forces that arise from muscle contraction and transduce them into body movements (e.g. mandibular excursive movements and occlusal forces). It harbors cavities containing bone marrow where blood cells are formed, which constitute an important source of nutrients (e.g., growth factors, proteins, and osteogenic precursor cells). Also, the bone tissue works as a reservoir of calcium, phosphate, and other ions that can be released or stored in a controlled fashion to maintain body homeostasis. The diversity of bone functionality is due to its complex structure; it is composed of calcified extracellular material called the "bone matrix" and three major cell types (osteocytes, osteoblasts, and osteoclasts), all of which have specific functions for the maintenance of healthy bone tissue.

Its mineral phase is enmeshed with organic fibers (type I collagen fibers embedded in a ground substance consisting of proteoglycans, glycoproteins, and inorganic minerals), and both minerals and collagen fibers are considered to be involved in the mechanical resistance of the tissue (Currey 1969a). The collagen fibers form bundles resistant to pulling forces, whereas the minerals provide stiffness to resist bending and compression forces (Currey 1969b). The minerals, mainly in the form of calcium phosphate (CaP) or hydroxyapatite (HA) crystals, may associate with collagen fibers, providing a specific hardness to the bone during a progressive and sequential mineralization of bone matrix.

The metabolites embedded inside bone are not capable of diffusing through the calcified matrix. The exchanges between osteocytes and microvasculature structures are mediated by very thin cylindrical spaces of the canaliculi and cytoplasmic elongations that connect the trapped cells "osteocytes" within mineralized tissue with the surface lining cells in an irreversible manner. All bones are lined on both internal and external surfaces, such as the "endosteum" surrounding the marrow cavity and the "periosteum" for external surface, respectively.

Basic Bone Anatomy

Macroscopically, bone may be classified into compact (cortical) bone that represents 80% of total bone mass and deeper areas with numerous interconnecting cavities called cancellous (trabecular or spongy) bone that represent the remaining 20%. Cortical bone consists of concentric layers of matrix surrounding longitudinal vessels, within Haversian systems, with mainly un-remodeled interstitial bone interposed between them that compose a framework of the bone, which is weaker than cortical bone but still provides metabolic support. The compact bone tissue is organized in cylindrical shaped osteonic structures that have concentric layers or lamellae surrounding a central canal or Haversian canal, a source of nutrients, nerves, and blood supply for bone maintenance. On the surface of the osteon, the boundary is formed by the cement line resultant of the bone remodeling process or the "de novo" bone formation, which is a concept drawn from bone fracture healing lessons (Davies 2003).

According to classical histology, bone tissue may be classified in relation to the spatial orientation of collagen fibers. Two different types of bone have been recognized through microscopic examination: woven-fibered bone and parallel-fibered bone (non-lamellar or lamellar) (Currey 1969a). Woven bone has a poorly structured matrix that is formed rapidly in response to wounding or hypertrophic adaptation. Parallel-fibered or lamellar bone results from a slower appositional rate, where a more highly organized matrix gives greater bone strength; the degree of mineralization is also related to the stiffness and strength of the bone (Traini et al. 2006).

There is evidence that variances in the orientation of collagen fibers within a bone matrix are associated with both mechanical loading and regimen (Riggs et al. 1993; Traini et al. 2005b). A previous report observes that forces exerted by biting and chewing have a significant effect on the variation in the preferential alignment of the c-axis in apatite crystals, as was demonstrated in monkeys (Nakano et al. 2002). This observation may be in part explained because the bone tissue has a specific anisotropic morphology derived from collagen fiber alignment, the related apatite crystal orientation as a bone quality index, and the osteoblasts cell orientation that seems to determine the crystallographic anisotropy of apatite crystals when a new osteoid matrix is developed (Matsugaki et al. 2015). Anisotropy is related to tissue that shows different mechanical characteristics under different strain conditions (different loading vector directions).

Woven Bone

Woven bone (WB) is non-lamellar and characterized by the random disposition of type I collagen fibers and is the first type of bone tissue to appear in embryonic development and fracture repair, such as implant bed drilling. This kind of bone is rich in osteocytes, which lie in lacunae that vary in size and shape, and is also indicative of rapid uncontrolled bone formation and high bone turnover. It is usually temporary and is replaced by lamellar bone, except in very few places of the body (e.g., near the sutures of the calvaria or in the insertion of some tendons). In addition to the irregular interwoven array of collagen fibers, this type of bone has a lower mineral content that is more easily penetrated by X-rays; an often higher proportion of osteocytes than mature lamellar bone reflects the fact that woven bone forms more quickly but has less strength than lamellar bone (Fig. 1).

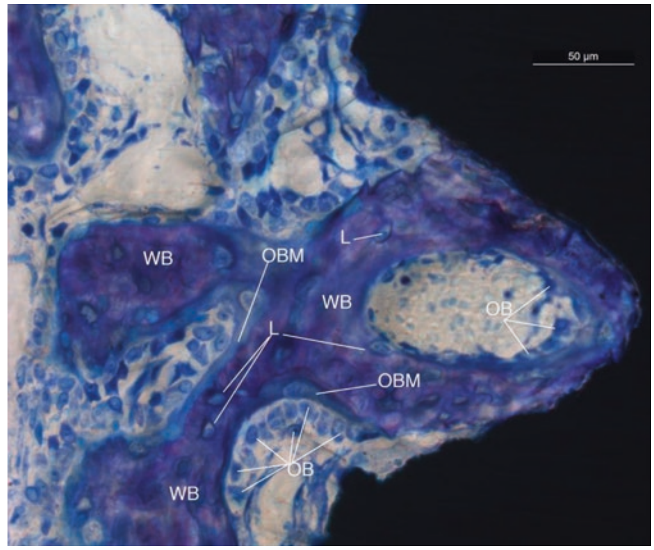

Fig. 1 Optical micrograph of woven bone (WB) in a rabbit model at 2 weeks of healing. The image depicts an uncontrolled and disorganized bone growth as a consequence of organic bone matrix (OBM) deposition by osteoblast, note the irregular distribution of fibrous matrix in a diffuse woven bone and the presence of some osteocytes embedded within lacunae (L). MG Inhex, Ticare® implants, Mozo-Grau, Valladolid, Spain

Lamellar Bone

Most bone in adults, cortical or trabecular, is organized as lamellar bone (LB), characterized by multiple layers or lamellae of calcified matrix, and it is organized either as parallel sheets or concentrically around a central canal. In each lamella, type I collagen fibers are aligned in parallel, with the pitch of the fibers orientation shifted orthogonally (by about 90°) in successive lamellae. This highly ordered organization of collagen within lamellar bone is visible under a polarizing light microscope as birefringence (alternating bright and dark layers are due to the changing orientation of collagen fibers in the lamellae "like wood fibers in plywood"), and its disposition confers greatly to the strength of lamellar bone.

An osteon is a bone functional unit or "Haversian system", and it refers to the complex of concentric lamellae surrounding a small central canal that contains blood vessel/nervous/adipose tissues and endosteum, and between each concentric lamellae there are lacunae with one osteocyte interconnected by canaliculi containing the cells' dendritic process, connected with the processes of neighboring cells through gap junctions. All cells of an osteon receive nutrients and oxygen from microvasculature in the central canal. This central canal is surrounded by 4–10 concentric lamellae that

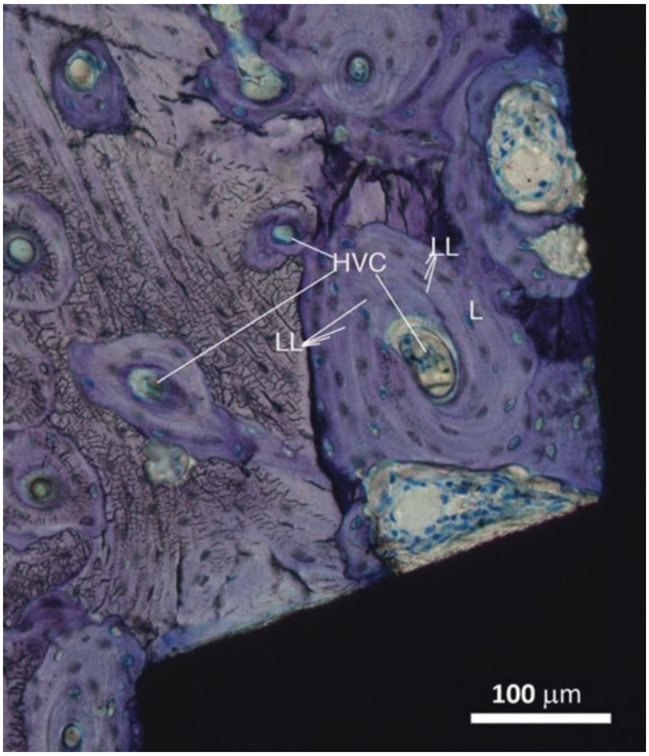

Fig. 2 Optical micrograph of the lamellar bone (LB) in a rabbit model at 8 weeks of healing. The histological image showed remodeling units "osteons" showing concentric layers of lamellae (LL) around Haversian canals (HVC) (vascular support). MG Quattro, Ticare® implants, Mozo-Grau, Valladolid, Spain

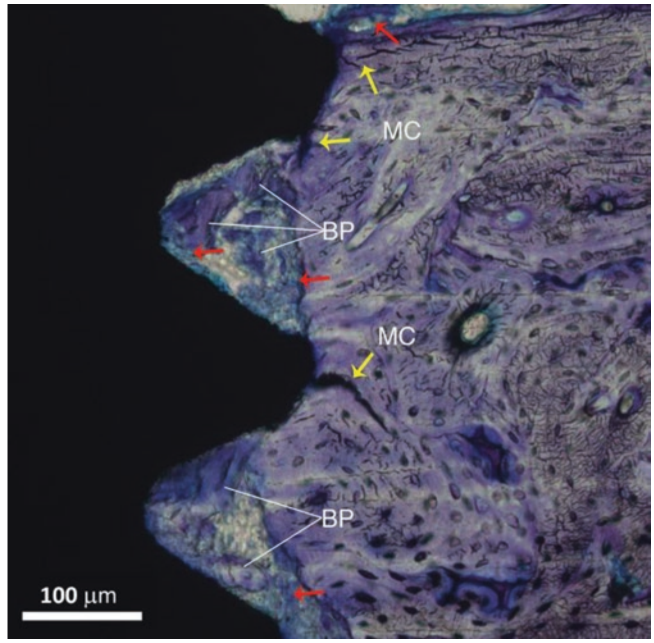

Fig. 3 Optical micrograph at 2 weeks of healing in a rabbit model. The bone-implant interface visually adverts a mechanical interlocking between parent bone of implant site and implant surface, which is responsible for the primary stability. At this period the presence of a microcrack (MC) in proximity to implant thread (yellow arrow), as well as old bone particles (BP) within the healing chamber, show that yield of bone strength surpasses the physiological limit due to the high stress in this area. It is denoted by an active remodeling establishment within the healing chamber and microcrack proximity (red arrow), compatible with an interfacial bone remodeling. Toluidine blue staining. MG Quattro, Ticare® implants, Mozo-Grau, Valladolid, Spain

communicate with the marrow cavity, periosteum, and other osteons through transverse perforating or Volkmann's canals, and it may have few, if any, concentric lamellae. All central and perforating canals come into existence when the matrix is laid down around areas with preexisting blood vessels. Scattered among the intact osteons are numerous irregularly shaped groups of parallel lamellae called interstitial lamellae that are lamellae remaining from osteons destroyed by osteoclasts during growth and remodeling of bone (Fig. 2).

Bone Remodeling

The bone replacement process in the adult skeleton is known as remodeling. When bone is removed by osteoclasts, new bone is laid down by osteoblasts in the same place, because the load bearing requirement is unchanged. Bone is usually replaced because it is too old to carry out its function, which is mainly mechanical in cortical bone and mainly support for homeostasis and hematopoiesis in cancellous bone. Remodeling always begins on a quiescent bone surface, separated from the marrow by flat lining cells that are one of the two modes of terminal differentiation of osteoblasts. Lining cells are gatekeepers, able to be informed of the need for remodeling, and to either execute or mediate all four components of its activation–selection and preparation of the site, recruitment of mononuclear preosteoclasts, budding of new capillaries, and attraction of preosteoclasts to the chosen site where they fuse into multinucleated osteoclasts (Parfitt 1994).

Both remodeling processes are developed through bone structure, the osteonal remodeling in cortical bone and a hemi-osteonal remodeling in spongious bone, that consists of osteoclastic resorption advancing on the bone "cutting cone", followed by osteoblastic activity making a new bone matrix "closing cone" (Parfitt 1994). Bone remodeling is designed to maintain a mechanically competent skeleton and to repair areas of microdamage. It is achieved by the ongoing process of mature bone removal and replacement by new bone formation, which implicates an osteoclastic cycle recruitment and activation through the subsequent initiation of osteoblast formation and repair resorption sites. Adult bone is continuously broken down by osteoclasts and rebuilt by osteoblasts, collaborating within 'basic multicellular units' (BMUs). Osteoclasts create a resorption cavity that is subsequently filled with new bone by osteoblasts (van Oers et al. 2008). Bone remodeling is depicted in Fig. 3.

Osteocytes, Osteoclasts, and Osteoblasts

Osteocytes

Osteocytes, the most abundant cells in bone, have been long postulated to detect and respond to mechanical and hormonal stimuli and to coordinate the function of osteoblasts and osteoclasts. The discovery that the inhibitor of bone formation sclerostin is primarily expressed in osteocytes in bone and downregulated by anabolic stimuli provided a mechanism by which osteocytes influence the activity of osteoblasts (Bellido 2014). Considered former osteoblast cells that become trapped in the bone matrix during bone formation, they inhabit the lacunar–canalicular system and communicate with other osteocytes and the surface lining cells, in part via gap junctions. Osteocytes elongate their dendrite processes and develop lacunar–canalicular systems that play an important role in bone remodeling (Zhang et al. 2006). Nowadays, the evidence suggests that osteocytes work as mechanoreceptors, and that they almost certainly sense rates of change of mechanical deformation (strain). They ultrastructurally demonstrated that mechanical loading via bone-integrated implants increased the number of spherical-shaped osteocytes in bone around dental implants, and they increased osteocyte dendrite processes in the implant neck. It is concluded that accelerated osteocyte responses to mechanical loading via bone-integrated implants may be associated with increased bone anabolism (Sasaki et al. 2015).

This occurs through a number of paracrine signals, including prostacyclin (PGI2), prostaglandin-E2 (PGE2), nitric oxide, and insulin growth factor (IGF), which are stimulated by osteocytes following changes in skeletal loading. Moreover, the findings show that expression of the glutamate transport by transporters (GLAST) has similar weight as in brain, but its expression in the plasmatic membrane of osteoblasts and osteocytes is increased following loading due to the presence of a splice variant, GLAST-1a, in bone tissue (Mason et al. 1997; Mason and Huggett 2002). It suggests that excitatory amino acids may play a role in the mechanotransduction of the loading strain.

Osteocyte apoptosis is spatially and temporally linked to bone fatigue-induced microdamage and to subsequent intracortical remodeling. Specifically, osteocytes surrounding fatigue microcracks in bone undergo apoptosis, and those regions containing apoptotic osteocytes co-localize exactly with areas subsequently resorbed by osteoclasts (Cardoso et al. 2009). Previous observations may be in part explained because osteocytes, not osteoblasts or lining cells, are the main source of the receptor activator of nuclear factor kappa-B ligand (RANKL) required for osteoclast formation in remodeling cancellous bone as recently reported (Xiong et al. 2015).

Osteoclasts

Osteoclasts resorb bone by attaching on the bone matrix and forming a sealing zone. Osteoclasts are large, multinucleated cells that can penetrate 50–70 μm into compact bone and resorb a volume of bone equivalent to that formed by osteoblasts. Osteoclasts possess numerous mitochondria and an extensive Golgi system but have a sparse endoplasmic reticulum and few ribosomes.

Osteoclasts are formed from hematopoietic mononuclear cells of the bone marrow, although the exact nature of the precursor cell is still a matter of debate. The regulation of osteoclast activity is complex, involving a variety of factors (including systematic hormones, such as parathyroid hormone, 1,25-dihydroxyvitamin D3, and calcitonin as well as numerous local factors). A number of these factors act through the generation of secondary signals by osteoclasts; mechanisms that are believed to couple bone resorption with bone formation. The mechanisms by which bone resorption is terminated include activation of matrix-derived transforming growth factor B (TGF-B), the presence of calcium sensor, and finally osteoclast apoptosis.

To maintain bone homeostasis by resorbing the bone, osteoclasts become differentiated from hematopoietic cells in response to stimulation by RANKL and macrophage colony-stimulating factor (M-CSF) produced by osteoblasts or osteocytes (Takayanagi 2007). RANKL signaling promotes expression and activation of the nuclear factor of activated T cells 1 (NFATc1), a transcription factor and master regulator of osteoclastogenesis, which upregulates the expression of various molecules that accelerate osteoclastic differentiation and bone resorption, such as dendrocyte-expressed seven transmembrane protein (DC-Stamp), osteoclast-associated, immunoglobulin-like receptor (OSCAR), 3 integrin, Src, and cathepsin K (Ikeda et al. 2006; Asagiri and Takayanagi 2007; Takayanagi 2007). During differentiation, osteoclast precursor cells fuse with each other, spread, and form the actin ring; a unique actin structure at the cell periphery (Zaidi et al. 2003; Jurdic et al. 2006; Takahashi et al. 2007). Osteoclasts strongly attach to the bone matrix, demarcate the bone-resorbing area by sealing it with the actin ring, and form a ruffled border to secrete bone-resorbing factors, such as protons and cathepsin K (Marchisio et al. 1984; Soriano et al. 1991; Boyce et al. 1992; Zaidi et al. 2003; Horne et al. 2005; Jurdic et al. 2006; Takahashi et al. 2007). Thus, the formation of the actin ring and ruffled border is necessary for bone resorption (Marchisio et al. 1984; Soriano et al. 1991; Boyce et al. 1992). The osteoclast structure is depicted in Fig. 4.

Osteoblasts

Osteoblasts are mononuclear, fibroblast-like cells found in a single layer on bone surfaces. An osteoblast forms a volume of matrix equivalent to its own size every day. The bone

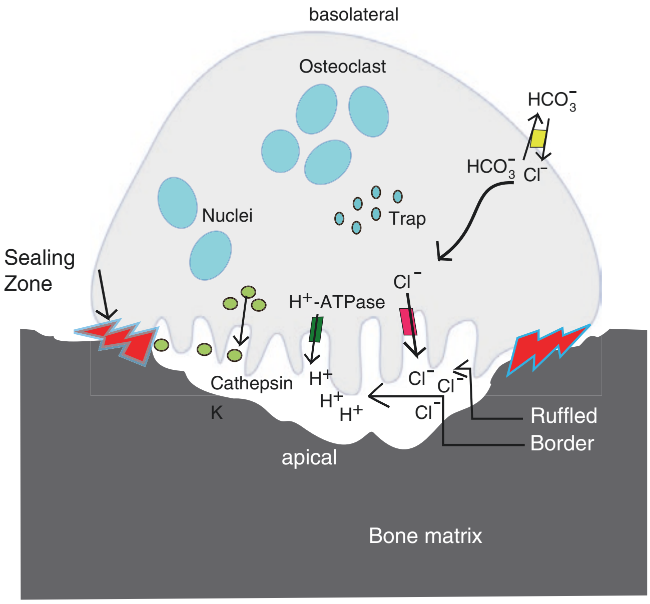

Fig. 4 Illustration of a functionally active osteoclast. Mature osteoclasts are large multi-nucleated cells that cover a big area on the bone to degrade the bone matrix. The apical membrane faces the bone and the sealing zone generates an isolated region. A ring of aggregated F-actin assures the strong attachment of the osteoclast to its substrate. The resorptive area is acidified by secretion of HCL to demineralize the bone matrix. Organic components are degraded by Cathepsin K. Osteoclasts express tartrate-resistant acid phosphatase (TRAP), which is commonly used as a marker for osteoclasts. Image adapted with permission from (Kubatzky et al. 2013)

matrix consists primarily of type I collagen and a number of noncollagenous proteins, such as sialoprotein, osteocalcin, and osteonectin (Rodan and Harada 1997). High concentrations of growth factors, such as TGF-B and insulin growth factor (IGF), are also secreted into the matrix. The control of osteoblast differentiation is poorly understood, because a multiplicity of factors is involved.

Adaptation of bone in response to load has been in part elucidated by (Rubin and Lanyon 1987). Under compression, the cortex is thicker and has an increased osteon density but has smaller osteons and less turn over, while the cortex under tension is thinner and has a higher turnover with larger, less numerous osteons (Skedros et al. 1994a, b). There are also differences in the degree of skeletal mineralization, with regions of bones that are under tension having a lower mineral density than those under compression (Currey et al. 1996). This is because tensile yield in compact bone is determined by strain and post-yield behavior by mineral content, so a greater mineral content means less post-yield work and less increase in post-yield stress and strain (Currey 2004). Cortical porosity has been investigated in relation to the principal loading mode, compression or tension. To maintain any level of bone mass requires a continued, loading-related osteoregulatory stimulus (Lanyon 1996; Liu et al. 2018). Furthermore, differing loading environments exerts an effect on the orientation of bone collagen fibers inside the bone matrix. Also, around dental implants, bone under compression has oblique transverse collagen fibers, while that under tension has longitudinal collagen fibers (Traini et al. 2005a, b, 2009; Delgado-Ruiz et al. 2015).

The Phenom of Osseointegration: Stages of the Peri-Implant Healing Process

Osseointegration is a dynamic process during its establishment and maintenance, characterized by resorption and apposition events, and the extent and degree of osseointegration is in part affected by implant surface configuration (Abrahamsson et al. 2004). This process is orchestrated and regulated by the expression of biological cues, proteins, and genes related to immune-inflammatory, skeletogenesis, angiogenic, and neurogenic responses (Ivanovski et al. 2011). Nowadays, osseointegration is considered by the international team for implantology (ITI) as possible with any biocompatible material capable of integrating within bone tissue, including commercially pure titanium, titanium alloys or zirconium oxide.

Osseointegration is marked by three distinct healing phases, and it is transduced in many stages involved, such as haemostasis, inflammatory, proliferative, and remodeling phases, resulting from communication and interaction between cells types (Terheyden et al. 2012)

As addressed experimentally (Davies 1998), three healing stages occur during endosseous implant integration: *osteoconduction*, "*de novo*" *bone formation, and bone remodeling*. These are not unique to peri-implant endosseous healing but also occur as an outcome of evolutionary development, during both bone remodeling and fracture healing, and can thus be considered as critical hallmarks of bone healing and regeneration. The combination of osteoconduction and bone formation will result in contact osteogenesis. The long-term remodeling of the tissue is influenced by different stimuli; the most important being the biomechanics of the developed healing site, and thus it should also be treated separately. Indeed, since trabeculae are damaged during implant site preparation, it is not surprising that bone fracture healing and peri-implant healing exhibit many similarities (Davies 2003).

Contact Osteogenesis: Osteoconduction and De Novo Bone Formation

The two healing phases involved, osteoconduction and de novo bone formation, result in contact osteogenesis given an appropriate implant surface and bone bonding. This distinction was thoroughly explored by Osborn and Newesley (1980), who described two different phenomena, contact and distance osteogenesis. It refers to the general relationship between forming bone and the surface of an implanted material. Though their classification was linked to different implant material types, rather than the biologic mechanisms underlying their histological observations, it still provided one of the most useful starting points to understand the mechanism of endosseous integration (Davies 1998).

Osteoconduction: The Key to Contact Osteogenesis

The first and most important healing phase, osteoconduction, relies on the recruitment and migration of osteogenic cells to the implant surface, through the residue of the peri-implant blood clot. Among the most important aspects of osteoconduction are the knock-on effects generated at the implant surface, by the initiation of platelet activation, which result in directed osteogenic cell migration through the release of platelet derived growth factors and molecules contained in plasma (e.g., TGF-B1, acid FGF, Trombin, BMP-2, and BMP-7). Osteoconduction also occurs during normal tunneling remodeling in bone. In such remodeling, differentiating osteogenic cells are derived from undifferentiated perivascular connective tissue cells (pericytes) (Jaworski 1981).

De Novo Bone Formation

The work of Osborn and Newesley (1980) is particularly important for understanding contact osteogenesis. However, their work omitted a critical step; that being the formation of the earliest mineralized matrix by differentiating osteogenic cells before they become mature polarized osteoblasts. This is the very stage at which, in normal bone remodeling sites, the osteogenic population secretes an initial matrix that provides the interface between old bone and new bone. Interestingly, this interface was first described 123 years ago by a German histologist, von Ebner, who coined the term "Kittiinien," or cement lines, to describe the mineralized interfacial matrix laid down between old bone and new bone. Although new bone is formed, the term "de novo" bone formation is restricted to describe the cascade of biological events that occurs during bone formation by newly differentiating populations of osteogenic cells.

Early Events During Osseointegration

The series of events leading to osseointegration encompassed coagulum formation, granulation tissue formation, development of a provisional matrix, woven bone formation, parallel-fibered bone formation, and eventually lamellar bone formation (Salvi et al. 2015). After implant installation, the thread was in contact with pristine bone and the pitches of the threads provided a mechanical anchorage in the pristine bone, providing the primary mechanical stability of the device (Raghavendra et al. 2005; Lioubavina-Hack et al. 2006). The void between the pitch and the body of the implant established a geometrically well-defined wound chamber (Abrahamsson et al. 2004). This chamber was filled with a blood clot characterized by the presence of erythrocytes, neutrophils, and monocytes/macrophages in a network of fibrin, and this tissue contained numerous mesenchymal cells, matrix components, and newly formed vascular structures (Davies and Hosseini 2000; Salvi et al. 2015).

Primary Stability and Interfacial Remodeling Healing Pathway

Arguably, one of the most important aspects for reaching a clinical osseointegration is the primary stability during implant placement (Lioubavina-Hack et al. 2006). In the first instance there is an implant fixture mechanical anchorage provided by parent bone walls of the implant bed preparation and the mechanical interlocking with implant threads and pitches during insertion. The extent of primary anchorage is tightly related to native bone characteristics, implant design, patient characteristics, and surgical technique, respectively (Meyer et al. 2004), all of which regulate to some extent the strain applied to mineralized tissue in the implant proximity (Petrie and Williams 2005; Isidor 2006; Gottlow et al. 2012). Also, strain is directly related to bone interfacial stress and frictional force transferred, clinically interpreted as insertion torque (N/cm) (Huang et al. 2011; Chowdhary et al. 2015). Even though this is the sole mechanical interlocking between the bone and the implant, there exists no biological interplay (Halldin et al. 2011; Norton 2013). Therefore, primary stability should not be regarded as osseointegration since it is the result of the osteoconduction of the implant system.

Higher primary stability is intuitively and fallaciously perceived as a higher value of insertion torque, which is a pre-requisite to clinically indicate procedures such as immediate loading (Esposito et al. 2008; Javed and Romanos 2010). This is due to the fact that the primary stability concept arises from the theoretical background in which bone mineralized tissue is considered an elastic material and both the strain and the implant stability will have a linear relation (Halldin et al. 2011). Although, this implant stability would decrease as a consequence beyond the yield strain of the bone due to the excessive microcracks formation and compression necrosis, which are events that trigger the peri-implant bone remodeling (Chamay and Tschantz 1972; Halldin et al. 2011). Smaller cracks (<100 μm) can also be detected during implant bed osteotomy preparation (Warreth et al. 2009), and longer cracks are often detected when the implant is placed in undersized implant sites (Bartold et al. 2011). Also, as previously reported, osteocyte apoptosis is induced by bone fatigue and localized to regions of bone that contain microcracks, and osteoclastic resorption after fatigue also coincides with regions of osteocyte apoptosis (Verborgt et al. 2000). This is because if the high strain applied surpasses the physiologic threshold, it results in a plastic deformation with numerous microcracks that alter pristine bone mechanical properties (O'Brien et al. 2005; Halldin et al. 2014); on the contrary, an elastic response occurs if strain is below the yield point.

Although, microcrack formation is regarded as an important phenomenon for the intracortical remodeling (Bentolila et al. 1998), excessive microcrack formation has the risk of generating a macrocrack (fracture) through the interconnection of unrepaired microcracks (Burr et al. 1997, 1998). A necrosis by compression takes place when the hard tissue around the implant is faced with excessive strain with a deleterious effect on capillaries and nerves, damaging its structure (Zizic et al. 1985). Therefore, depending on implant design and surgical technique (instrumentation dimension), a variable degree between implant and parent bone friction and interlocking may occur leading to higher or lower insertion torque, equivocally interpreted by several clinicians as proportional to implant primary stability due to the fact that experimental evidence demonstrates that there is an inverse relationship between insertion torque and immediate micromotion; being unrelated in particular for those implants with the least insertion torque (Bashutski et al. 2009; Freitas et al. 2012). Also, a recent study reported that the more implant insertion force used, the lower the primary stability obtained through resonance frequency; although, different forms of an implant system need different insertion torques to obtain an optimal primary stability (Staedt et al. 2017).

In summary, nowadays, high insertion torque should be questioned because elastic theory predicts that excessive strain may provoke deleterious biologic effects on bone response and its biomechanical stability depending on the implant thread design. A primary stability decrease as a consequence of the cell mediated remodeling of surrounding pristine bone toward the implant surface (resorption and apposition), which was theoretically proposed by (Raghavendra et al. 2005) and further corroborated experimentally by (Jimbo et al. 2014a), confers from this perspective the implant stability dip, where high degrees of implant stability go down to lower levels. This occurs when it is reached through a mismatch between implant macro-design and surgical instrumentation dimensions or because the strain generated by thread tip is slight highly than the physiological limit and consequently generates a stability loss through a cell-mediated interfacial bone remodeling that is thereafter regained through bone apposition (Raghavendra et al. 2005; Jimbo et al. 2014b). Interfacial bone remodeling is depicted in Figs. 3 and 5.

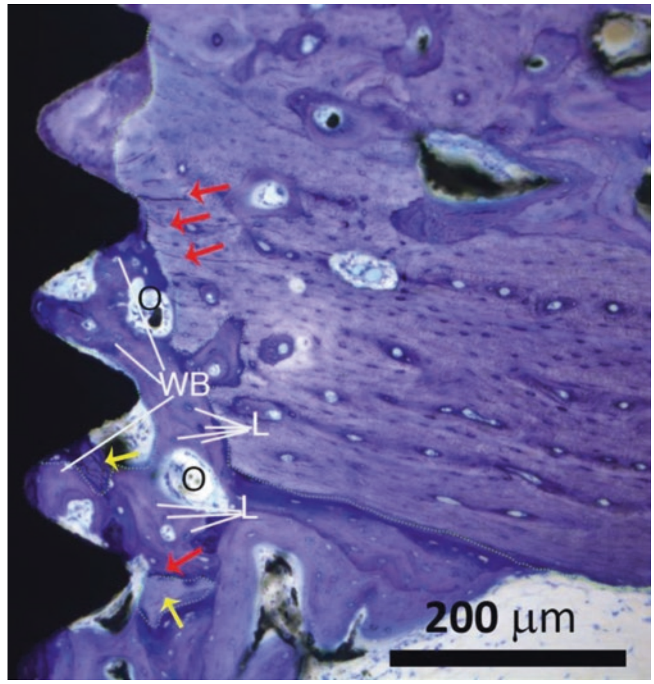

Fig. 5 Optical micrograph at 4 weeks of healing in a rabbit model at 10×. Remodeling across healing chambers is evident, remodeling sites occur in the proximity of microcracks (red arrows). The resorbed area will be replaced by woven (WB) bone, which reestablishes the contact to implant surface (secondary stability); subsequently, the new primary osteons (O) will arise with some osteocytes trapped within lacunae (L). Tissue remodeling occurred at the interface where cell-mediated processes resorbed the region encompassed between the green dashed line and the implant. MG Inhex, Ticare® implants, Mozo-Grau, Valladolid, Spain

Sequential Healing During Osseointegration

The sequential healing at three stages based on a rabbit model with resorbable blast media (RBM) surface dental implants is developed as follows; it is pertinent to take into account that the healing process in this experimental model occurs faster than in humans (Botticelli and Lang 2017).

Week 2: The healing process remains in its initial phase. There is an evident accelerated proliferation of blood vessels and mesenchymal cells embedded inside the provisional granulation tissue that stimulate the formation of an immature peri-implant primary bone; this bone modeling is observed in healing chambers by the presence of a cell-rich immature bone or woven bone (WB). High magnification evaluation showed woven bone formation throughout the extension of the healing chamber region, with loci of diffuse woven bone and lines of osteoblasts depositing bone matrix. This 'contact osteogenesis' is considered to represent the very first phase of osseointegration, namely direct contact between the roughened implant surface and newly formed woven bone as depicted in Fig. 6.

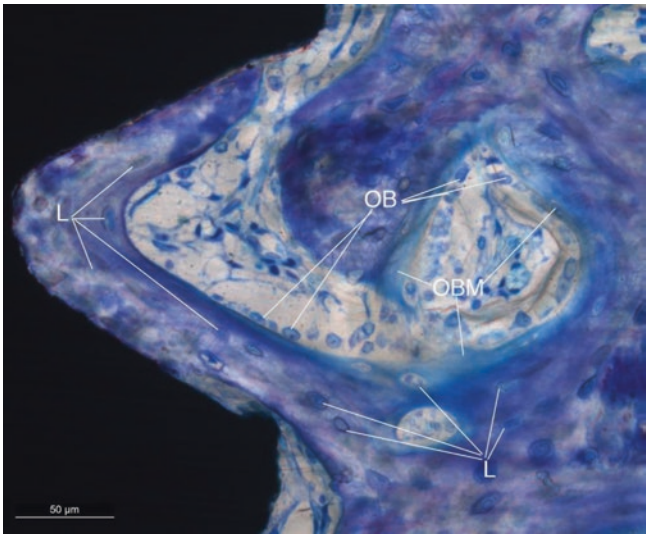

Fig. 6 Optical micrograph at 2 weeks in vivo in a rabbit model. The non-mineralized woven bone (WB) within the healing chamber is observed. There are also some osteoblast (cube-shaped cells) secreting organic bone matrix perceived by the light blue color (OBM) and some lacunae in the proximity (L) suggesting the presence of osteoblasts trapped in bone matrix that get converted to osteocytes. The image depicted at this stage suggests a high activity of the cellular content. Toluidine blue staining. MG Inhex, Ticare® implants, Mozo-Grau, Valladolid, Spain

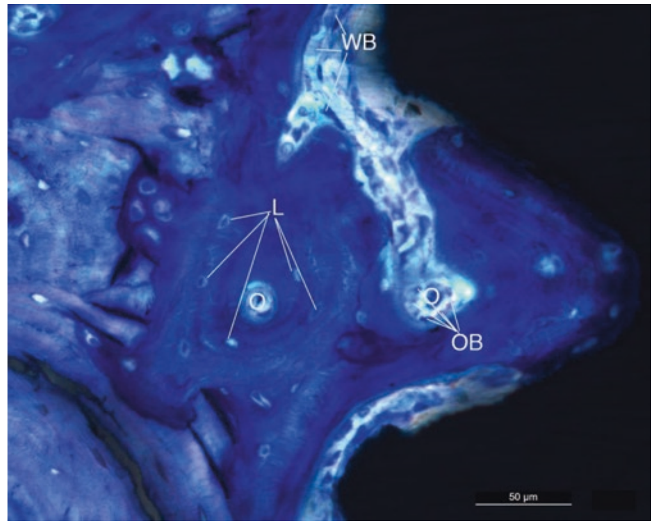

Fig. 7 Optical micrographs at 4 weeks in vivo in a rabbit model. How the woven bone (WB) is progressively replaced by a more organized lamellar bone (LB) surrounding primary osteonic structures (O) is observed, and some osteoblasts (cube-shaped cells) secrete organic bone matrix within osteon lumen in a circumferential manner. There are some lacunae within lamellar bone distributed in a concentric manner. Toluidine blue staining. MG Inhex, Ticare® implants, Mozo-Grau, Valladolid, Spain

Simultaneously, osteoclast formation occurs on the pristine bone, resulting in bone resorption adjacent to the implant surface, especially in areas of pressure of the implant to the bony bed (i.e., pitches of the threads) that provided initial fixation for the implant, had undergone resorption, and were also involved in new bone formation after 2 weeks of healing. Mechanical stability of the implant was replaced by secondary biological stability.

Week 4: The healing progress at this stage shows the woven bone (WB) replacement by lamellar bone (LB), suggesting an initial remodeling has begun. It is evidenced by the presence of primary osteonic structures (O) that elucidate the onset of WB remodeling toward LB configuration surrounding blood vessels. Also, lacunae in LB was present behind the mineralizing bone front, where the bone organic matrix is secreted and deposited circumferentially toward osteonic lumen by osteoblastic cells, and this osteonic structure constitutes a source of nutrients, blood vessels, and mesenchymal cells. The healing at this stage is depicted in Fig. 7.

Week 8: The bone throughout the healing chambers clearly shows a "bone remodeling" process, with the presence of parallel fibered lamellar bone deposition, and there is plenty of bone formed, evidenced by the presence of primary and secondary osteonic structures. Lamellar osteons (haversian systems) outlined by cement-line boundaries are visible. The bone trabeculae had become reinforced, thus providing a structure to cope with load bearing (Fig. 8). There is a mixed bone morphology with regions of woven and lamellar bone because the remodeling process is still occurring at this stage (Fig. 9).

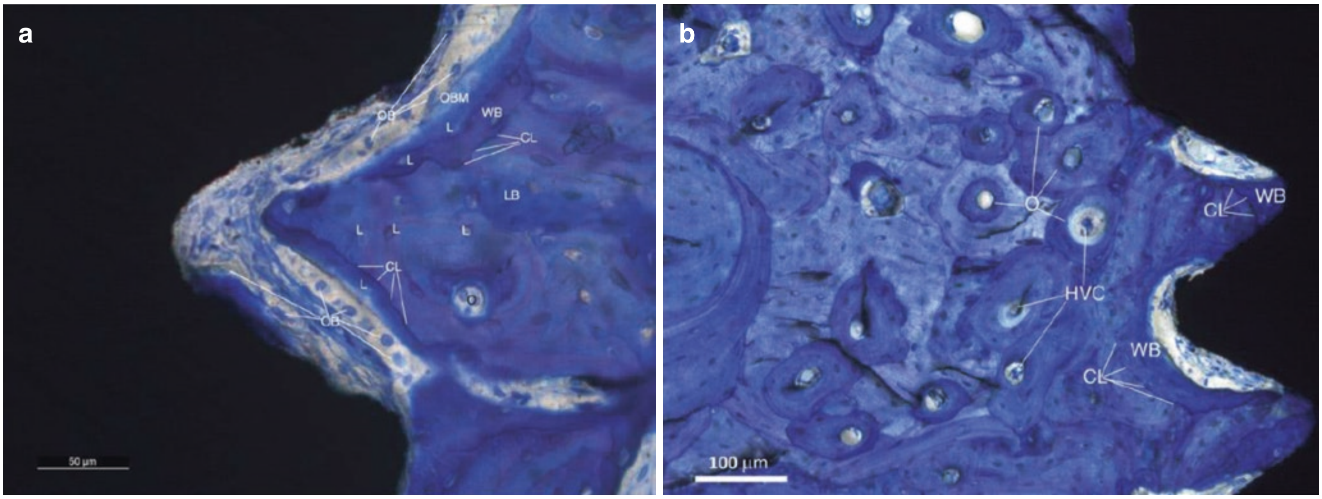

Fig. 8 Optical micrographs at 8 weeks in vivo in a rabbit model. (**a**) The bone remodeling still occurs within the healing chamber in the proximity of the implant surface, it is denoted by the presence of woven bone (WB) with some osteoblasts (OB) depositing organic bone matrix (OBM) characterized by a light blue staining and lacunae (L) with trapped osteocytes. The WB is surrounded by lamellar bone showing primary osteonic structures (O), which revealed the onset of woven bone remodeling toward lamellar configuration surrounding blood vessels, outlined by reversal "cement lines" that differentiate the mineralized from non-mineralized compartments. (**b**) The presence of primary and secondary osteonic structures (O) with their own Haversian's system canals (HVS) could be clearly observed. At this stage the mature bone is capable of resisting load bearing. Toluidine blue staining. MG Quattro, Ticare® implants, Mozo-Grau, Valladolid, Spain

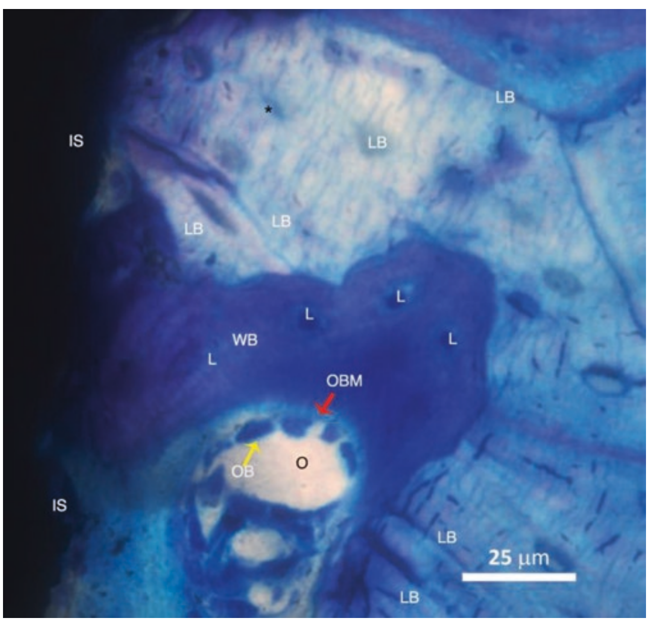

Fig. 9 Optical micrograph at 8 weeks in vivo in a rabbit model. A mixed bone morphology is evidenced with regions of woven bone (WB) characterized by a "more intense" staining color and lamellar bone (LB) "less intense" staining color surrounding osteonic structures (O). There is new bone formation in the contact implant surface (IS) at the expense of lamellar bone remodeling, the presence of osteocytes is visible in LB (black asterisk) and trapped in lacunae (L), behind the organic bone matrix (OBM) deposition by osteoblast cells (OB) disposed circumferentially within osteon lumen (yellow arrow), and they are denoted by the light blue color (red arrow). Toluidine blue staining. MG Quattro, Ticare® implants, Mozo-Grau, Valladolid, Spain

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Histological Evaluation of Early and Immediately Loaded Implants Retrieved from Human Jaws

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Abbreviations

BIC	Bone-implant contact
DLMS	Direct laser metal sintering
HA	Hydroxyapatite
ZrO_2	Zirconium implant

Take-Home Messages

- Retrieved dental implants are the only way to evaluate the short- and long-term response of human bone tissue and to corroborate the results of in vitro and of animal experimental studies. It is then essential to study well-integrated dental implants with surrounding human bone tissue.
- Moderately rough implant surfaces are, probably, the best in terms of bone response.
- Loading of the implant changes the microstructure of the peri-implant bone.
- Immediate loading does not create problems to the formation of mineralized tissues at the interface with dental implants and has, probably, a beneficial effect on the peri-implant bone response.
- Osseointegration is a very dynamic ongoing process, and the peri-implant bone tends to become more organized over the years; these higher degrees of organization are reflected by the multiple remodeling areas within the mature, lamellar bone, indication of multiple remodeling cycles over the years of loading.
- Remodeling, very well-organized, mineralized, lamellar bone is found at the interface of retrieved implants even after three decades of loading.
- Bone remodeling is a prerequisite for dental implants to support functional loading in the long term.
- Bone-implant contact (BIC) and bone mechanical properties tend to increase over time, and the bone tissue tends to adapt to loading to increase its biomechanics.
- In all well-integrated retrieved implants, excellent bone-implant contact is found, with mineralized, mature, lamellar bone in close and tight contact with the implant surface, at all regions of the implant perimeter, with no sign of migration of the epithelium or formation of connective tissue.
- In our specimens, the bone-implant contact percentage varied greatly from 32–37% to more than 90–95%. This fact means that implants may have a successful function over a wide range of degrees of osseointegration. Even implants with a low bone-implant contact percentage were stable, well-integrated, and able to bear loading conditions over the years.
- Mineralized bone was not found, in unloaded implants, at the base of the threads and, in loaded implants, at the tip of the threads.
- Osteocytes (the mechanosensors in the bone) were found in the peri-implant bone. Their number was significantly

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higher in loaded implants when compared with unloaded implants.

- The number and thickness of bone trabeculae were significantly higher in loaded implants.

Introduction

Osseointegrated dental implants have been proven to have a high long-term success in several clinical indications with high survival and success rates, but some of them will still fail (Degidi et al. 2009a, b, 2010a; Erkapers et al. 2011; Salvi et al. 2004). In vitro studies can help in trying to find some answers (Gandolfi et al. 2015). Many animal studies have been performed to evaluate, for example, different implant macrogeometries, different implant surface topographies, different loading conditions, different bone qualities and quantities, etc. (Abrahamsson et al. 2004; Cesaretti et al. 2018; Han et al. 2014; Kuroshima et al. 2015; Piattelli et al. 1998, 2002, 2003; Quaranta et al. 2008; Steigenga et al. 2004; Yamamoto et al. 2014). All these studies are extremely valuable; they are, however, of a low evidence quality, and the results obtained from these studies could not be automatically transposed to a human situation. Accordingly, it is very important to evaluate retrieved human implants (Coelho et al. 2009; D'Avila et al. 2010; Degidi et al. 2003a, b, c, 2008, 2009c, 2010b; Di Stefano et al. 2006; Iezzi et al. 2007, 2009b, 2012, 2016; Mangano et al. 2009, 2015, 2017a, b; Piattelli et al. 2014; Proussaefs et al. 2002; Rocci et al. 2003; Romanos et al. 2005; Scarano et al. 2004, 2006; Shibli et al. 2008; Traini et al. 2014; Uehara et al. 2004). These implants can be removed due to a wide range of technical and biological problems (they are failing or have already failed), e.g., mobility, fracture, peri-implantitis, bone resorption, infection, etc. (Mangano et al. 2015; Traini et al. 2014). They can also be obtained for other reasons such as psychological reasons, unrestorable prosthetics, misalignment, pain, dysesthesia, not optimal position from an esthetics and hygienic point of view, inability of an implant to meet changed prosthetic needs, or can be retrieved at autopsy (Proussaefs and Lozada 2004; Rocci et al. 2003). In all these latter cases, the retrieved implants present an excellent bone anchorage. Implants from humans can also be obtained as part of a research protocol approved by an Ethical Committee using experimental implants with reduced dimensions (micro-implants) or temporary implants to support an interim restorations (D'Avila et al. 2010; Mangano et al. 2009). In all these cases, the bone tissue anchorage is still present and allows an important source of biological evidence of bone-implant contact (BIC). The careful evaluation of all these different types of implants can also be extremely useful to help in understanding the failure modalities or the reactions of the peri-implant tissues (soft tissues and bone) (Albrektsson 2008; Coelho et al. 2009; Traini et al. 2014). The concept of osseointegration was based initially on a histological definition, but there are no histomorphometrical diagnoses of osseointegration because we do not know the precise values of the BIC percentages that are required by an implant to meet the requirement to be defined osseointegrated (Iezzi et al. 2016; Mangano et al. 2015). A histological and histomorphometrical evaluation of a large series of retrieved implants could help to give some answers in this field (Coelho et al. 2009; Iezzi et al. 2016). The Implant Retrieval Center of the University of Chieti-Pescara, Italy, has been working continuously since mid-1988. In that time, a very large quantity of retrieved human implants have been treated to obtain thin ground sections and have been evaluated histologically and histomorphometrically.

In this chapter, the main focus will be on our long-term experience (about 30 years) on implants with different surface characteristics, on implants retrieved after different loading periods, on the long-term outcome of the hydroxyapatite coating, on implants retrieved from grafted sites, on implants retrieved from post-extraction sites, on implants inserted in patients suffering from metabolic conditions as osteoporosis, on implants retrieved from smokers, on the peri-implant soft tissues, and finally on the peri-implant bone response to early and immediately loaded implants.

Dental Implant Surfaces

The initial healing period of an implant is the phase of the osseointegration process that is primarily affected by the surface condition of the implant (Abrahamsson et al. 2004; Degidi et al. 2009c, 2010c; Gandolfi et al. 2015; Mangano et al. 2017a, b; Piattelli et al. 2014). With roughened surfaces, there is an increase of the bone-implant contact (BIC) percentage (Mangano et al. 2015, 2017a, b; Piattelli et al. 2002). The amount of BIC plays an extremely important role in long-term implant survival (Iezzi et al. 2016; Mangano et al. 2015; Sagirkaya et al. 2013).

When an implant is placed into a bone site, a cascade of biological events is initiated. There is a recruitment and migration of osteogenic cells to the implant surface. Then, new bone formation takes place, which results in the formation of a mineralized interfacial matrix, followed by bone remodeling processes (Gandolfi et al. 2015; Iezzi et al. 2016; Mangano et al. 2015) (Fig. 1). It is important to emphasize, on the other hand, that the surface characteristics of an implant are not the only requirements to obtain a long-lasting implant anchorage. The implant material, bone quality and quantity, surgical technique, surface characteristics, implant design, and implant loading conditions are all related to the implant long-term success. The percentage of BIC may be employed to evaluate the stability of an implant, and values

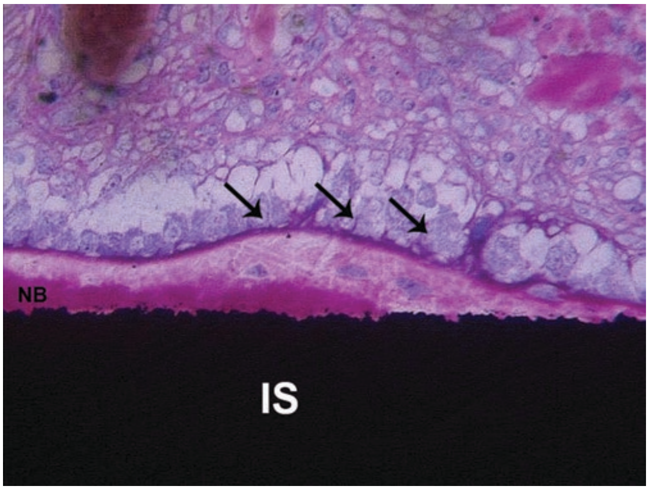

Fig. 1 Newly formed bone (NB) in close contact with the implant surface (IS). A rim of osteoblasts (arrows) is depositing osteoid matrix on the implant surface (contact osteogenesis). (Acid fuchsin-toluidine blue 200X)

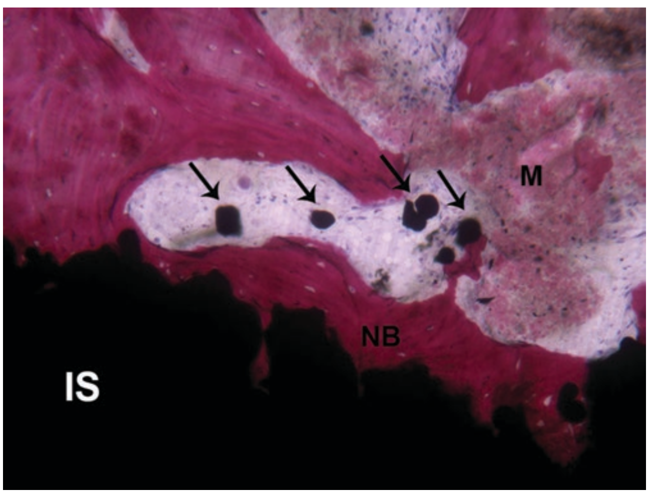

Fig. 2 The newly formed bone (NB) grows inside the implant surface (IS) irregularities. Few small particles (arrows) detached from the implant surface can be observed. Far from the implant surface, a not yet mineralized matrix (M) is present. (Acid fuchsin-toluidine blue 100X)

higher than 50% appear to be satisfactory, even if lesser values of BIC have been reported around stable implants after years or decades of loading (Coelho et al. 2009; Iezzi et al. 2016; Mangano et al. 2015). Torque removal value (RTV) has been used to describe the anchorage of an implant to the bone, and the higher the value, the greater the biomechanical strength of the bone-implant interface (Degidi et al. 2010b; Scarano et al. 2006) (Fig. 2). We have already said that results obtained in studies performed in humans are more reliable than the findings obtained in studies performed in animals or in vitro. Some studies can, however, be performed using an animal model (Cesaretti et al. 2018; Han et al. 2014; Piattelli et al. 1998; Quaranta et al. 2008; Vandamme et al. 2007), e.g., RTV evaluations of implants with different macro-and microgeometries, and in vitro studies can be useful in helping to understand the biological response of different types of cultured cells in contact with different implant surface topographies (Gandolfi et al. 2015).

Each surface should be described by the combination of parameters representative of height and space (Albrektsson 2008). Albrektsson (2008) reported that surfaces showing a moderate roughness with an Sa value of 1.5 microns and a SDR value of 50% showed the best and strongest bone interlocking.

Machined Surfaces

Were the most commonly used in the past. These surfaces were also called "turned" or "smooth," and microscopic observation under scanning electron microscopy revealed the presence of a slight roughness due to the grooves and ridges produced during the turning process. One of the main characteristics of the machined surfaces was that the bone growth pattern was characterized by "distance osteogenesis," i.e., bone growth toward the implant surface (Fig. 3) (implantopetal kind of bone growth) (Mangano et al. 2017b).

Sandblasted Surfaces

Were produced by blasting the metal with different types of blasting or gritting agents. This process was influenced by the number and the size of the particles used. The blasting procedure served to increase the irregularities of the implant surface of the implant, by using agents such as aluminum

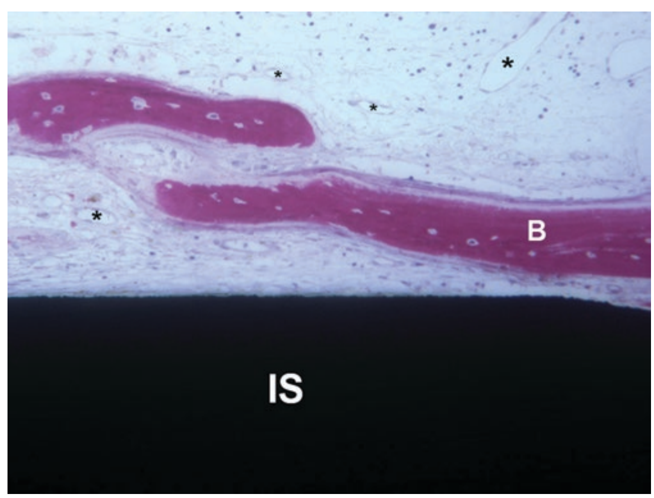

Fig. 3 Machined surfaced implant. Bone (B) is growing toward the implants surface (IS): distant osteogenesis. In the marrow space, many blood vessels (*) are present close and far from the surface. (Acid fuchsin-toluidine blue 100X)

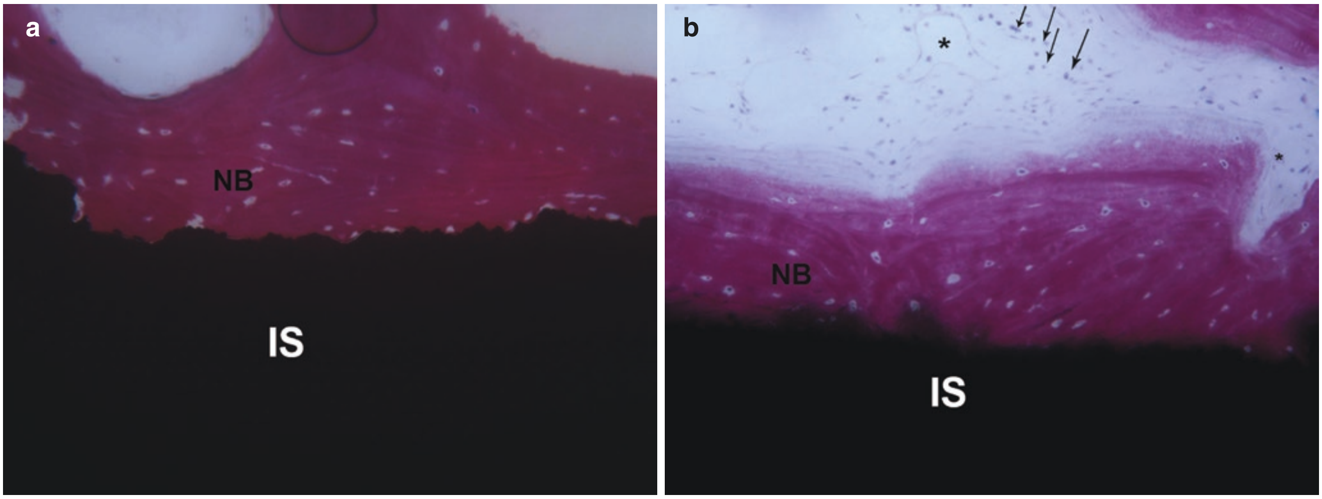

Fig. 4 (**a**) Newly formed bone (NB) filling the irregularities of the implant sandblasted surface (IS). (Acid fuchsin-toluidine blue 100X). (**b**) Close to the newly formed bone (NB), in tight contact with the implant sandblasted surface (IS), few blood vessels (*) and many stromal cells (arrows) can be observed. (Acid fuchsin-toluidine blue 100X)

oxide (Al_2O_3) or titanium oxide (TiO_2). The large variability in surface appearance under scanning electron microscopy (SEM) of different implant surfaces is due to the different techniques employed in the blasting procedure. The sandblasted surfaces have shown, in in vitro studies, a higher adhesion, proliferation, and differentiation of osteoblasts. Higher BIC values were found in histological studies that compared blasted and turned surfaces (Iezzi et al. 2012). Blasting procedures leave, however, blasting residual particles on the surface of the implant, and this fact could modify the bone healing process (Piattelli et al. 2003). Some researchers think that aluminum ions could impair bone formation by a possible competitive action to calcium, while others suggested that histological data did not provide evidence to support the hypothesis that residual aluminum oxide particles on the implant surface could affect the osseointegration of titanium dental implants (Piattelli et al. 2003). The bone growth pattern around blasted, rough surfaces is characterized by “contact osteogenesis,” i.e., the osteoblasts start depositing osteoid matrix directly on the implant surface (“implantofugal type of growth”) (Piattelli et al. 2002) (Fig. 4a, b). This type of bone growth could produce an earlier and a higher quantity of bone at the interface with the implant (Mangano et al. 2017a, b).

Plasma Sprayed Surfaces

These kinds of surfaces have been used in orthopedics since many decades. These implants were prepared by spraying heat molten metal on the titanium base, which resulted in a surface with irregularly sized and shaped valleys and peaks, pores, and cavities with an increase of the implant surface area by 6–10 times. This surface topography, in which it was possible to observe the formation of bone into the coating, improved the implant fixation in bone, by a biomechanical interlock (Piattelli et al. 1998) (Fig. 5). One disadvantage of this type of surface could be the detachment of titanium particles from the coating after implant insertion. The implications of this occurrence were, however, not clear.

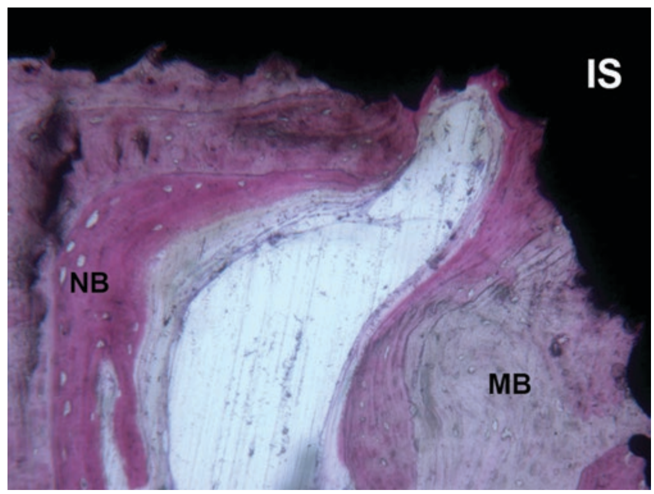

Fig. 5 Mature (MB) and newly formed bone (NB) are present in contact with the plasma-sprayed implant surface (IS) many years after implant placement. (Acid fuchsin-toluidine blue 100X)

Acid-Etched Surfaces

They were introduced to modify the implant surfaces without the residues found after the blasting procedures, to have a more uniform surface treatment, and to control the loss of

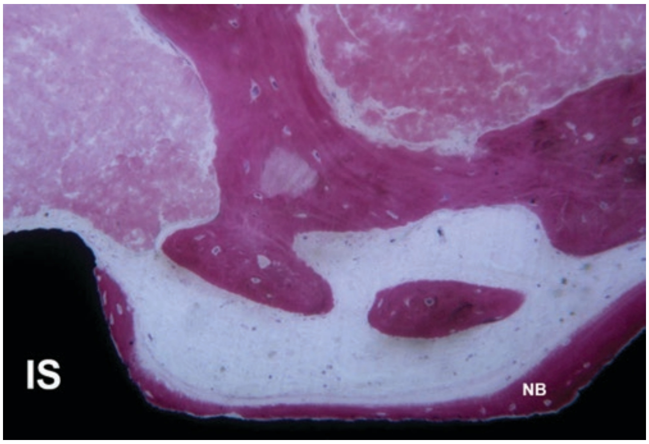

Fig. 6 A layer of newly formed bone (NB) is growing within the thread of an acid-etched surfaced implant (IS) (contact osteogenesis) but distant from the trabecular bone. (Acid fuchsin-toluidine blue 100X)

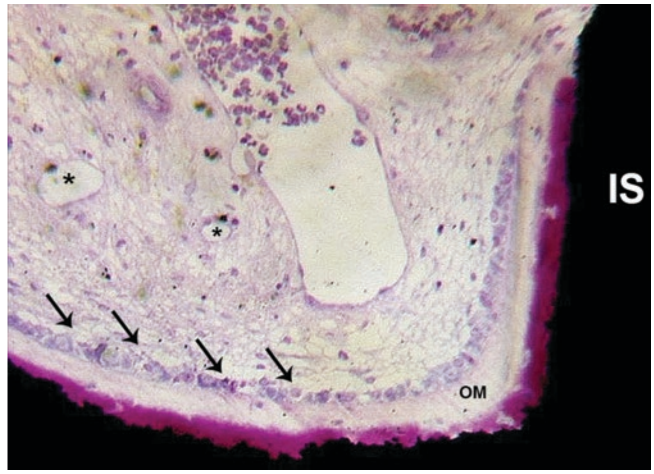

Fig. 7 A thin bone trabeculae is forming on the concavity of a sandblasted and acid-etched implant (IS). Osteoblasts (arrows) are depositing not yet mineralized osteoid matrix (OM) (contact osteogenesis). In the marrow space, it is possible to observe small and large blood vessels (*). (Acid fuchsin-toluidine blue 100X)

metallic substance (Degidi et al. 2003c). Baths using chloride (HCl), sulfuric (H_2SO_4), hydrofluoric (HF), and nitric (HNO_3) acids, in different combinations, have been used. The acid-etching process was affected by the acid used, by the bath temperature, and by the etching time. The bone growth pattern was "contact osteogenesis" (Degidi et al. 2003c) (Fig. 6).

Sandblasted and Acid-Etched Surfaces

Surfaces obtained with a combined procedure of blasting (to produce a macro-texture) followed by acid etching (to produce a final microtexture). Sandblasted and acid-etched implants promoted a higher BIC at earlier time points compared to plasma-sprayed-coated implants. Sandblasted and acid-etched surfaces showed high osteoconductive properties and capabilities to induce cell proliferation (Iezzi et al. 2016) (Fig. 7).

Anodized Surfaces

These kinds of surfaces were obtained by modifying the structure of the superficial oxide layer of the implant surface without depositing grit particles. Anodized surfaces were prepared by applying a voltage on the titanium specimen immersed in an electrolyte. The resultant surface presented micropores of variable diameters (Rocci et al. 2003).

Hydroxyapatite (HA) Coatings

This kind of surface had a similar roughness and increase in surface area as that observed with titanium plasma spray surfaces (Fig. 8). A direct bonding to bone was observed, and the strength of the HA-to-bone interface was greater than that observed of titanium to bone and even greater than that seen in titanium plasma-sprayed surfaces and bone. In addition, accelerated interfacial bone formation and maturation have been observed in dogs. Gap healing, i.e., the healing in the space between the implant and bone, could be enhanced by the HA coating. The advantages of an HA coating are increased surface area, increased roughness for initial stability, stronger bone-implant interface, faster healing at the interface, increased gap healing, and less corrosion of metal. The coating may, however, flake or crack upon insertion, especially into dense bone. The increased surface roughness could increase the risk of bacterial contamination should the coating be found outside the bone, e.g., in cases of peri-

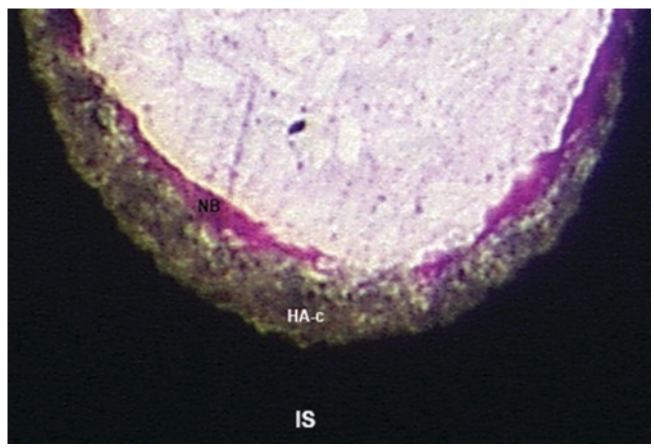

Fig. 8 Newly formed bone (NB) in contact with an hydroxyapatite-coated (HA-c) implant (IS). (Acid fuchsin-toluidine blue 100X)

implant crestal resorption. There is also an increased cost of the coating, compared with uncoated implants (Iezzi et al. 2009a; Proussaefs and Lozada 2004).

Zirconia

Zirconium oxide is used in implantology for its biocompatibility, esthetics (its color is similar to the tooth), and mechanical properties. The ZrO_2 implants are biocompatible, bioinert, and radiopaque and present a high resistance to corrosion, flexion, and fracture; ZrO_2 implants have been reported to show a bone and soft tissue contact similar to that seen around titanium implants, and ZrO_2 can be used to produce an entire implant, or as a coating (Scarano et al. 2004).

Bioceramic Molecular Impregnation

The surface properties in the nanometer range may modulate the characteristics of the protein layer adhesion to the implant surface, and the nanoscale structure of the extracellular matrix provides a natural web of nanofibers to support the cell structure. Dental implants with physical and bioceramic incorporation surface treatments at the nanometer range presented higher BIC and torque values compared with rough implant surface topography at the micrometer level. The application of nanotechnology for the alteration of texture and chemistry in dental implant topography may result in different cell behaviors, i.e., from alterations in adhesion, orientation, mobility, and surface antigen display of the cells of the pre-osteogenic and osteogenic lineage. Moreover, features in the nanometer range may also affect the adsorption and conformation of integrin-binding proteins, modifying the availability of binding sites and the integrin signaling (Scarano et al. 2003).

Direct Laser Metal Sintering Implant Surface

Previous studies from our Laboratory have shown that direct laser metal sintering (DLMS) procedure produces structures with complex geometry that show better osteoconductive properties (Mangano et al. 2009) (Fig. 9). Cells cultured on the DLMS implant surfaces showed a similar cell density to that observed on rough surfaces, but lower than that observed on machined surfaces. Moreover, it was shown that implants obtained through DLMS, having an elastic modulus closer to that of the bone, showed a better adaptation to the elastic properties of the bone (Fig. 10). DLMS implant topography not only minimizes stress-shielding effects, but also improves implants long-term success rates. These observations also suggested that

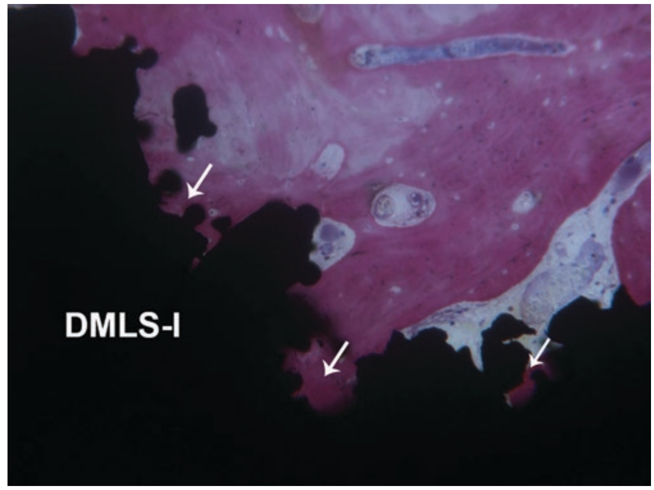

Fig. 9 Direct metal laser sintered implant (DMLS-I) the bone tissue grows inside the implant surface irregularities (arrows). (Acid fuchsin-toluidine blue 100X)

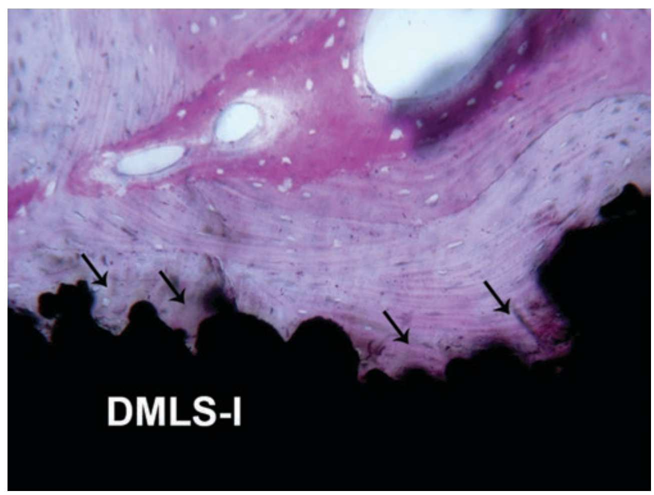

Fig. 10 The direct metal laser sintered surface (DMLS-I) is extremely irregular but enables bone growth around and within its indentations (arrows). (Acid fuchsin-toluidine blue 100X)

DLMS technique is an economical method for producing implants from commercially pure titanium or alloys (Mangano et al. 2009).

Implants Retrieved After Different Time Periods

Bone undergoes remodeling, with a transformation of the initially produced woven bone into a bone with a lamellar configuration, showing a higher degree of organization (Coelho et al. 2009; Di Stefano et al. 2006; Iezzi et al. 2016; Kuroshima et al. 2015; Mangano et al. 2015; Vandamme et al. 2007, 2008). With the passing of time, a still higher

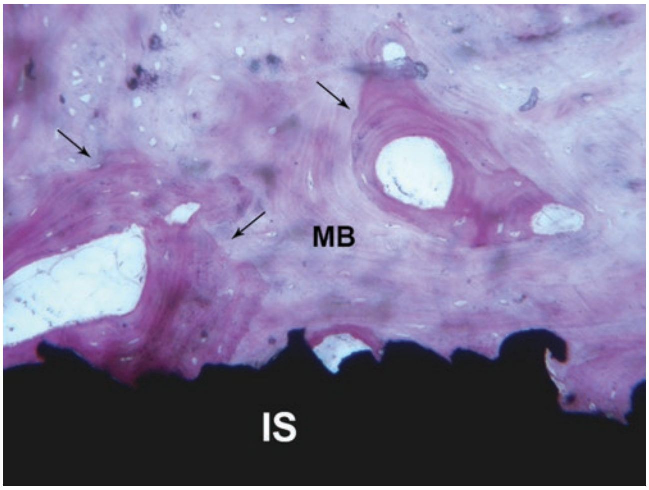

Fig. 11 Mature, lamellar bone (MB), with many remodeling areas lined by thin reversal lines (arrows), is observed in close contact with the implant surface (IS). (Acid fuchsin-toluidine blue 100X)

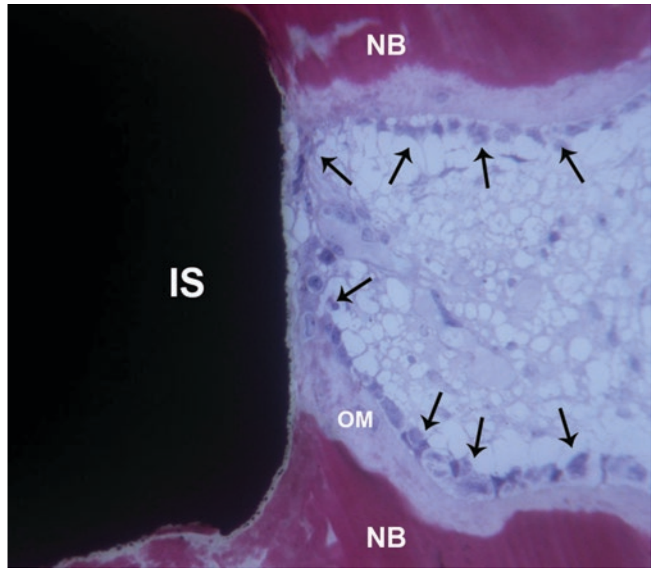

Fig. 12 A circular rim of osteoblasts (arrows) is depositing osteoid matrix (OM) in contact with the implant surface (IS) and with the newly formed bone (NB). Inside the osteoid matrix, few osteoblasts are entrapped and will turn into osteocytes. (Acid fuchsin-toluidine blue 200X)

degree of organization of the peri-implant bone can be observed with the formation of many areas of remodeling (Coelho et al. 2009; Iezzi et al. 2009b, 2016) (Fig. 11). A submerged healing period of 3–4 months has been thought to be necessary to obtain mineralized bone at the interface of dental implants, and an earlier implant loading has been reported to determine the occurrence of fibrous tissue at the bone-implant interface. On the other hand, several researchers have reported, in the last two decades, that in early and immediately loaded (IL) implants, placed in good-quality bone, it was possible to obtain a high level of osseointegration, clinically, radiographically, and histologically similar to that of implants used with a standard submerged protocol (Cesaretti et al. 2018; Degidi et al. 2007a, b; Eccellente et al. 2010; Gapski et al. 2003; Iezzi et al. 2016; Linkow and Miller 2004; Romanos 2004) (Fig. 12). Cesaretti et al. (2018) found a higher BIC value in delayed implants when compared with immediately loaded implants. Same results were reported in a meta-analysis of Sagirkaya et al. (2013). On the other hand, previous experimental work done in our Laboratory has shown a higher quantity of bone in immediately loaded implants when compared with control, submerged implants (Piattelli et al. 1998). Similar results were reported in a proof-of-principle human study (Degidi et al. 2009c). Moreover, very high implant survival rates for early and immediately loaded implants have been reported in the literature (Degidi et al. 2009a, 2010a). Many patients found the wearing of provisional prostheses rather uncomfortable, and most certainly the possibility to shorten the healing time without jeopardizing the dental implants long-term success would be beneficial for most of them. Immediate loading has been reported to be a viable and successful treatment option. However, the generalization from the results of the clinical trials to everyday routine dental practice should always be made with extreme caution because in most trials the inclusion criteria were very strict, only very good candidates for the implant therapy were included, and the clinicians were high skilled. Primary implant stability and lack of micromovement were considered to be the main factors involved in the success of IL implants (Degidi et al. 2010c). Macroretention offered by implant thread could reduce the risk of implant movements in the case of immediately loaded implants. Rigid splinting with minimal lateral forces decreased the amount of micromotion during the early healing phase, giving the implant a higher tolerance to deleterious micromotion. Healing processes were strongly influenced by the local mechanical loading history. In well-integrated implants retrieved from humans, it was possible to observe peri-implant lamellar bone organized in Haversian systems; these systems close to the implant surface were structured mainly in a parallel way, because the remodeling processes occurred, probably, from the implant surface in an outward direction (Iezzi et al. 2016, Mangano et al. 2015). Some authors found also that, under transmission electron microscopy, the orientation of the collagen fibrils was parallel to the implant surface (Shah et al. 2014). Mechanical stimuli regulated cell division and differentiation and determined the tissue type and architecture. Many osteocytes were located closely to the implant surface, indicating their importance as mechanosensors (Piattelli et al. 2014; Shah et al. 2014) (Fig. 13). Well-controlled implant loading seemed to accelerate the formation of mineralized tissues at the interface (Vandamme et al. 2007, 2008). Histological evidence of clinical successfully osseointegrated implants was rare in the

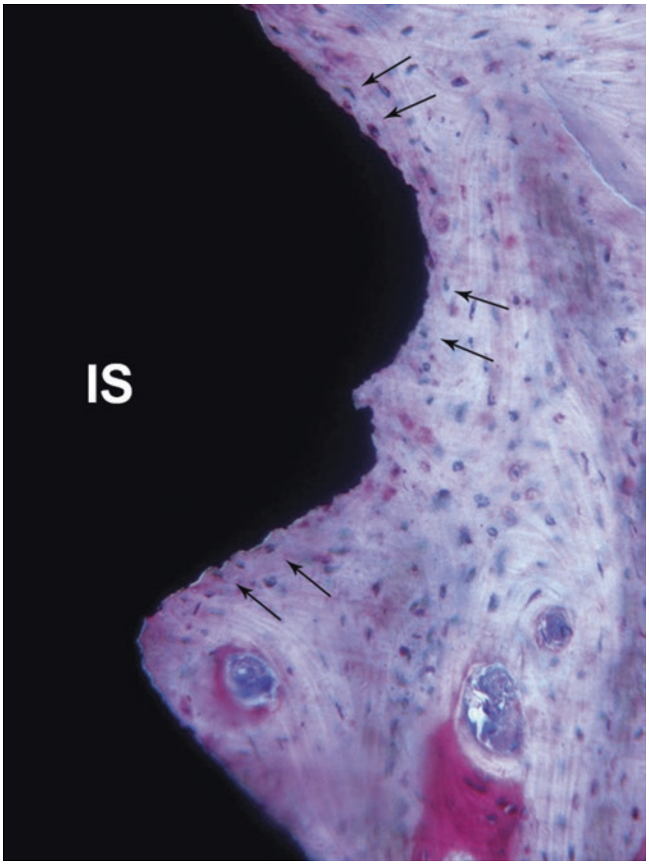

Fig. 13 Many osteocytes (arrows) are present at the level of the peri-implant bone, very close to the implant surface (IS). (Acid fuchsin-toluidine blue 100X)

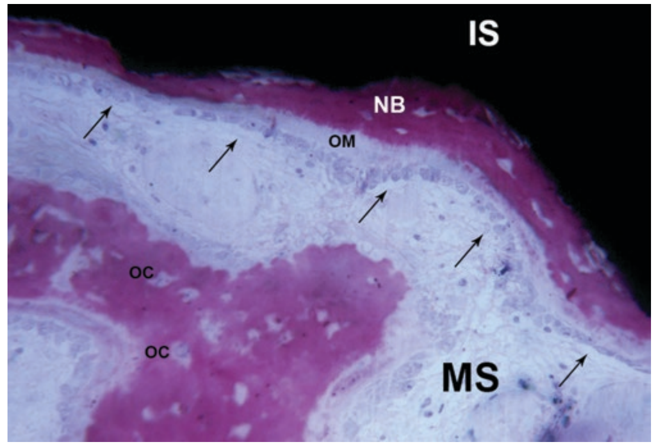

Fig. 14 Newly formed bone (NB) lines the implant surface (IS) and is in turn lined by osteoid matrix (OM) newly deposited by a rim of osteoblasts (arrows). Small newly formed trabeculae with wide osteocyte lacunae (OC) are present inside a marrow space (MS). (Acid fuchsin-toluidine blue 200X)

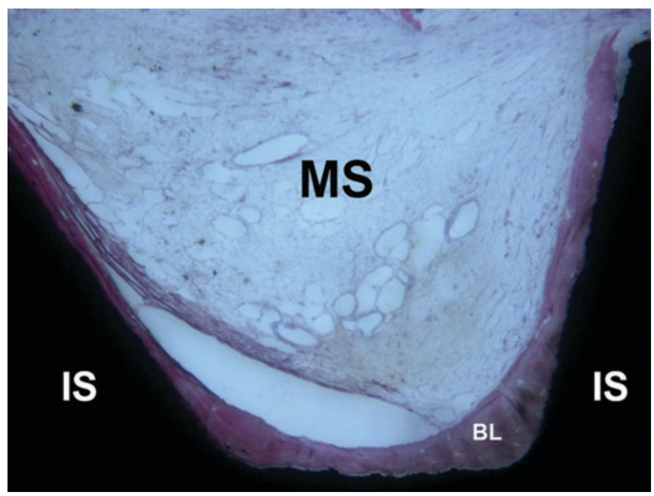

Fig. 15 Implant inserted in a low quality bone. It is possible to observe a thin bone lamella (BL) in contact with the implant surface (IS) and inside a large marrow space (MS), where a loose connective tissue is present. (Acid fuchsin-toluidine blue 100X)

literature, especially after a period of functional loading of more than 1 year (Coelho et al. 2009; Di Stefano et al. 2006; Iezzi et al. 2009a, b, 2012, 2016; Mangano et al. 2015; Piattelli et al. 2014; Proussaefs and Lozada 2002; Scarano et al. 2004; Traini et al. 2014). Moreover, it could also, perhaps, be useful to evaluate the healing evens at the interface after different time periods. The hardness and the elastic modulus of the bone tend to increase over time, and this fact could suggest that osseointegration is a very dynamic process with the occurrence of the adaptation of the bone to the functional loading stimuli in order to improve the overall bone biomechanics (Piattelli et al. 2014).

Histological data pertaining to IL implants demonstrate that IL did not produce untoward effect in the bone healing. Histological evidence showed that, even with shorter healing periods (4, 6, 8 weeks), it was possible to observe the formation of mineralized tissue at the interface (Fig. 14) (Degidi et al. 2008, 2009c).

Even in poor bone sites, a high bone-implant contact percentage was observed (Mangano et al. 2017b) (Fig. 15). In the spongious area, an almost continuous thin shell of newly formed bone usually covered the implant surfaces. Mineralized tissues were found covering a large portion of the implant surface with no foreign body or inflammatory reactions visible. Bone remodeling was present in areas around the implants. The histological and histomorphometrical analysis on the interface of immediately loaded implants inserted in low-quality bone and retrieved from humans showed a high percentage of BIC (Mangano et al. 2017a, b).

In conclusion, the data from the observations of the interface of retrieved, clinically stable, immediately loaded implants showed that, independent of whether they were placed in the maxilla or the mandible and the implant design, the immediate loading allowed new bone formation at the interface of dental implants. High BIC percentages seemed to be possible in early and immediately loaded implants (Degidi et al. 2008; Mangano et al. 2017a, b).

Implants Inserted in Poor Bone Sites

An important parameter that influences the long-term success of oral implants is the bone quality of the implant bed. Posterior areas of the jaws have been avoided in implant dentistry due to their poor bone quality, higher chewing forces, and presumed higher implant failure rates. In a meta-analysis of articles on human-retrieved implants conducted by Sagirkaya et al. (2013), these authors found that the mean BIC of implants in the mandible (70.97%) was higher than those in the maxilla (53.24%) and that the mean BIC in the anterior mandible (79.42%) was higher than that of the posterior mandible (69.14%). These authors concluded that the BIC of implants in the mandible was about 25% higher than that of implants located in the maxilla, due to a higher bone density in the mandible. They found also a 10% higher BIC in the anterior mandible than the posterior mandible and a 25–30% higher BIC in the anterior maxilla than the posterior maxilla (Sagirkaya et al. 2013), and they concluded that BIC was in a way related to the local bone density. Albrektsson (2008), in a retrospective study on more than 700 implants retrieved from humans, found that maxillary implants had a mean BIC of >50%, while the mandibular implants had a mean BIC of >75%. This same author underscored, however, the fact that we do not know if implants with a higher BIC have a higher percentage of long-term clinical success than implants with lower values of BIC. Soft bone-implant sites have been deemed by several researchers to be a great potential risk situation, and most failures have been found in sites where the bone density from the start was low. Increasing the rate of early endosseous integration was a critical goal to achieve improved success rates. The surface microtexture of the implants has been shown increasingly to be of relevant importance in the early stages of osseointegration. Some microstructured surfaces have an improved characteristic of contact osteogenesis even in soft bone, with coverage of the implant surface by a bone layer as a base for intensive bone formation and remodeling. A high BIC was observed even in implants inserted in poor bone sites (Mangano et al. 2017a).

HA-Coated Implants

A coating of the titanium surface with a layer of hydroxyapatite (HA) has been proposed to get a higher osseointegration rate, a faster attachment to bone tissue and a stronger bonding to bone, a reduction in the healing time, a higher interfacial strength to bone, an enhancing of the load stress distribution to the surrounding bone, and a better maintenance of the bone crest height. Concerns about the degradation of the coating over the years have been raised: it has been speculated that the resorption of the HA could produce a space between implant and bone with a resultant mechanical instability. There is a risk for degradation of the coating, which can weaken the bone bond giving rise to implant failure (Proussaefs and Lozada 2004). There have been some concerns about the long-term integrity of the coating in vivo and the fact that the dissolution and detachment of the coating could expose the underlying metal surface. It has been hypothesized that this fact could have adverse effects on interfacial bone-implant apposition and on the bone-implant interface stability. Moreover, the breakdown of the coating could produce particulate material with phagocytic response by macrophages or a foreign body reaction. Furthermore, implant failure has been associated with the loss of coating integrity, and studies of failed HA-coated orthopedic femoral stems have shown areas of coating degradation and separation. Moreover, the duration of the advantage of the HA coating is unclear. Coating dissolution and detachment from the titanium surface have been described histologically. There is some controversy whether the loss of the HA coating could be detrimental to the integration of the implant (Iezzi et al. 2009a). Porous HA is resorbed through physicochemical dissolution and cell-mediated phagocytosis. Additional dissolution may be due to the phagocytic and enzymatic action of macrophages recruited to the surface. However, histological studies have shown that after many years of function, HA-coated implants continued to demonstrate adequate BIC percentages (Iezzi et al. 2009a). This fact seemed to support the view that an adequate stability of the HA-coated prostheses was maintained despite the coating loss. In some specimens, the almost complete resorption of the HA coating didn't appear to have interfered with the osseointegration processes (Iezzi et al. 2009a). In these cases, the HA coating resorption, probably, did not have a great clinical significance because the implant was osseointegrated and was still providing an adequate function. Haversian systems were observed in close proximity to the implant surfaces in HA-coated implants, and this fact pointed to a physiologic remodeling activity of the peri-implant bone (Iezzi et al. 2009a). No foreign body reaction was observed associated with the HA particles that appeared to be detached from the coating (Iezzi et al. 2009a). These particles were always surrounded by bone.

Implants in Patients with Osteoporosis

Osteoporosis is a disease that influences the quality of bone tissue so that it may become susceptible to fracture. While animal studies have described the deleterious effect of osteoporosis on osseointegration, no clinical studies showed a clear association between implant failure and osteoporosis. The mechanism by which osteoporosis acted on peri-implant bone was based on the decrease in both cancellous bone volume and BIC, consequently reducing bone tissue to support dental implants. However, in studies in humans, BIC was found to be similar for both osteoporosis and non-osteoporosis subjects (Shibli et al. 2008). In conclusion, the results of the histomorphometrical studies, in implants retrieved from humans, suggested that osteoporosis might not present an absolute contraindication for implant placement, at least, after osseointegration has been established (Shibli et al. 2008).

Immediate Post-extraction Implants

Subsequent to the removal of all teeth in the adult individual, the alveolar processes will undergo atrophy. Marked alterations of the height and width of the alveolar ridge will occur following single or multiple tooth extractions. The healing process following tooth removal apparently resulted in more pronounced resorption on the buccal than on the lingual/palatal aspects of the ridge. So, after tooth extraction, the resorption and remodeling of the alveolar socket could result into a site that would be inadequate, from a dimensional point of view, for the implant placement. When an implant was placed into an extraction socket, osteogenic and osteoresorptive responses were already initiated following extraction, and this tissue could enhance the capacity for healing (Paolantonio et al. 2001). An immediate implant is one implant that was placed into an extraction socket at the same time the tooth was extracted. Immediate post-extraction implants have several advantages such as fewer surgical procedures, preservation of bone volume, and shortening of the time needed until the implants could be restored (Degidi et al. 2007b). Additional advantages of the use of the immediate post-extraction implants were:

1. Shortening of the edentulous time period
2. Reducing the costs of treatment
3. Improve the psychological approach with the patient
4. Reduction of the comprehensive treatment time with less surgical procedures and morbidity
5. Optimal esthetic result, with an easier definition of the implant position as a consequence of correct fixture position and angulation
6. Improvement of biomechanics of the future restoration

Several different human clinical studies have demonstrated that with immediate post-extraction implants, it was possible to obtain very high (more than 90%) long-term success percentages. Moreover, many experimental studies have confirmed that a high percentage of bone-implant contact could be achieved on light microscopic level in animals, when using immediate post-extraction implants (Degidi et al. 2007b; Paolantonio et al. 2001). One major drawback in using immediately post-extraction implants was due to the lack of adaptation of the alveolar bone in the cervical portion of the implant. Soft tissues, creating problems in the osseointegration of the implant, could fill this space. Almost always, when using immediate post-extraction implants, it was necessary to resort to guided bone regeneration techniques, with the use of biomaterials and membranes. However, in a histological study aimed to evaluate the outcome of implantation in fresh extraction sockets without the use of membranes in humans in comparison with implants placed in healed, mature alveolar bone, no significant differences in the clinical and radiographic parameters were observed between the two experimental categories (Paolantonio et al. 2001). Bone resorption was not present in any area of the histological sections (Paolantonio et al. 2001).

Implants Inserted in Grafted Sites

The successful outcome of a sinus augmentation procedure can be evaluated best by a histological examination of the events at the bone-implant interface. A successful implant osseointegration in sinus augmentation procedures should be characterized by a high quantity of newly formed bone at the implant interface, to provide enough bone for mechanical support and integration of the implants (Scarano et al. 2004). A bone substitute material should have the capability to allow the integration of loaded titanium implants. One of the most important questions about sinus augmentation procedures is if the regenerated bone obtained after the insertion of a graft is able to integrate dental implants. Other important questions are the extent of the surface of a dental implant placed into a grafted sinus, which will be surrounded by bone in direct contact with the implant surface, and to what extent functional ankylosis will be present and if the obtained implant osseointegration will remain stable over the long period, after functional loading (Fig. 16). Very high BIC was reported in implants retrieved from sinuses augmented after a period varying from some months to several years (Iezzi et al. 2007; Scarano et al. 2004). All these implants had osseointegrated and had remained osseointegrated after many years of functional loading (Iezzi et al. 2007; Scarano et al. 2004) (Fig. 17). It has been reported that grafted particles in contact with the implant surface could reduce mechanical support for the dental implants. No contact was, however, observed between grafted particles and implant surfaces in most of the reported implants (Iezzi et al. 2007; Scarano et al. 2004). The continued presence of grafted particles in the peri-implant bone did not seem to jeopardize the

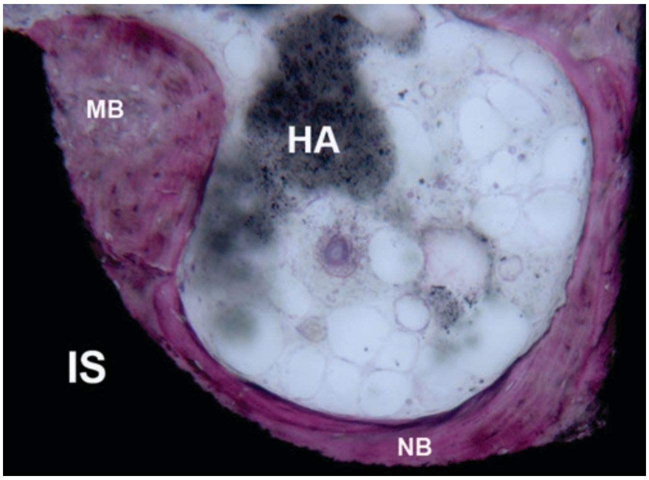

Fig. 16 Newly formed (NB) and mature bone (MB) match with the thread shape without gaps at the interface. A marrow space with loose connective tissue and remnants of partially resorbed synthetic hydroxyapatite (HA) not in contact with the implant (IS) can also be observed. (Acid fuchsin-toluidine blue 100X)

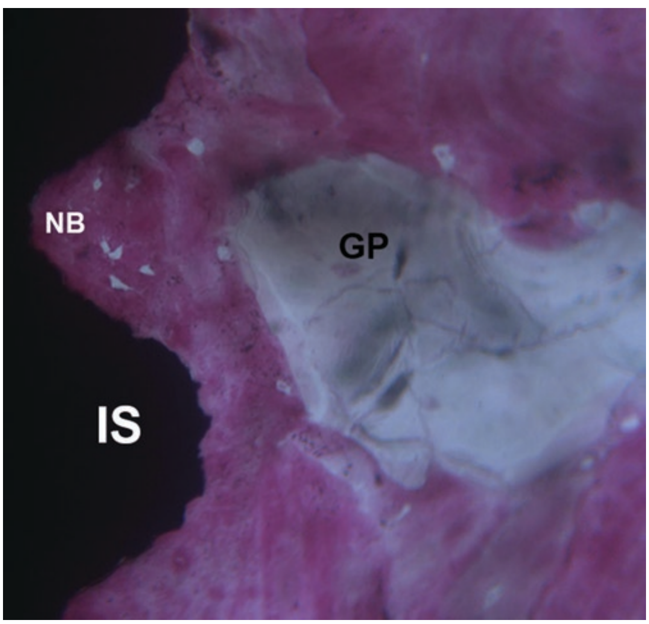

Fig. 17 Implant inserted in a grafted site. It is possible to observe newly formed bone (NB) in contact with the implant surface (IS). A residual grafted particle (GP) of heterologous origin is present far from the implant surface. (Acid fuchsin-toluidine blue 200X)

integration of the implant because no contact between the grafted particles and the implant surface was observed, and a complete resorption of the grafted material did not seem to be a prerequisite needed to get formation of bone at the interface and implant osseointegration (Iezzi et al. 2007; Scarano et al. 2004). On the other hand, the lack of complete resorption of the grafted material could even be advantageous in order to maintain the initial dimensions of the grafted area with time. Other human histologic specimens retrieved from grafted sinuses after longer time periods will certainly help to clarify the question of the biomaterial resorption over time and of the potential of regenerated bone to achieve and maintain osseointegration with dental implants. Provisional implants are helpful in helping the patients to avoid the inconveniences of wearing a denture and they can provide useful information after retrieval (Iezzi et al. 2007).

Implants in Smokers

The influence of smoking on peri-implant bone has been evaluated in a several histologic animal models. The majority of these studies agree that smoking had a detrimental effect on bone healing, BIC, and bone mineral density. Smoking delays the normal bone healing process by a mechanism that inhibits proliferation of precursor cells. Cigarette smoke is composed by over 4000 toxins that have the potential to undermine the peri-implant bone healing. Toxins such as nicotine, carbon monoxide, nitrosamines, benzenes, aldehydes, and hydrogen cyanide have been shown to affect essential processes of bone healing. Nicotine is a potent vasoconstrictor that not only reduces blood flow and nutrient delivery to the surgical implant site but also inhibits the proliferation of fibroblasts, red blood cells, and macrophages. Carbon monoxide decreases the oxygen-carrying capacity of red blood cells, while hydrogen cyanide leads to hypoxia. In human-retrieved specimens, BIC% was found to be significantly lower in smokers (Fig. 18). A tendency toward slower wound repair has been suggested. Moreover, cigarette smoking reduced the rate of bone formation and increased the rate of bone destruction in postmenopausal women. Cigarette smoking seemed to suppress osteoprotegerin levels and might contribute

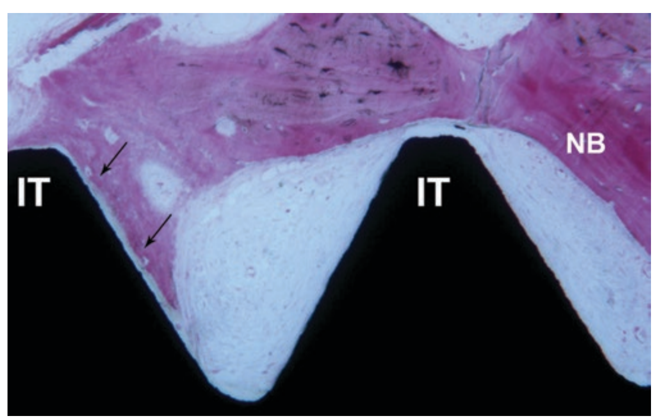

Fig. 18 Implant inserted in a smoker. A low-quality newly formed bone (NB) can be observed around the implant threads (IT). Only in a very small portion of the interface there is a contact between bone and implant surface (arrows). (Acid fuchsin-toluidine blue 40X)

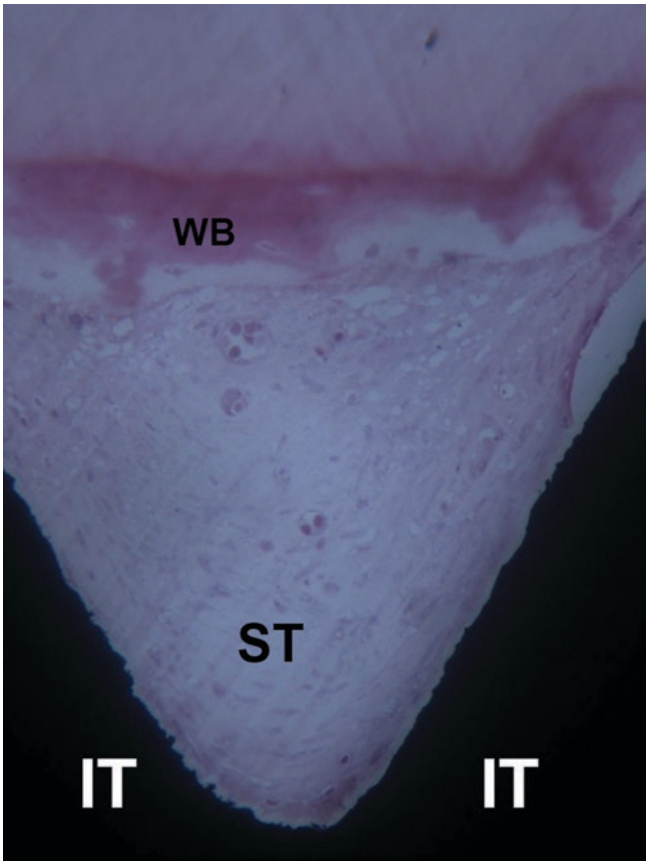

Fig. 19 Soft tissue (ST) is present inside the implant thread (IT). The new peri-implant woven bone (WB) does not contact the implant surface. (Acid fuchsin-toluidine blue 100X)

toward the decreased peri-implant bone formation (Fig. 19). However, the precise mechanisms by which smoking exerted its deleterious effects on bone healing remain unclear (D'Avila et al. 2010).

Basic Concepts About Immediate Loading

The concept of immediate loading was proposed more than 50 years ago when the endosseous blade implants were introduced (Linkow and Miller 2004). Histological evidence of osseointegration in clinically successfully osseointegrated implants in man can be found in the literature (Coelho et al. 2009; Degidi et al. 2003a, b). Retrieved human implants are extremely important for long-term evaluation of implants subjected to functional loading (Di Stefano et al. 2006; Iezzi et al. 2012, 2016; Proussaefs et al. 2002). Immediate loading of dental implants was thought to produce a fibrous repair at the interface. Therefore, the most important question is if an implant with a high primary stability in bone can be immediately loaded without formation of fibrous tissue at the interface. Primary stability seems to be a very important factor in immediate loading protocols (Yamamoto et al. 2014). Stability of an implant has been found to be related to implant geometry, implant length, surface morphology, splinting of implants, control of occlusal functional loads, bone quality, size of the host recipient site, and lack of detrimental patient habits (e.g., bruxism) (Yamamoto et al. 2014; Mangano et al. 2017a). Several histological reports, in man and experimental animals, have shown mineralized tissues at the interface in early and immediately loaded implants. Specifically, in monkeys (Piattelli et al. 1998; Quaranta et al. 2008), dogs (Cesaretti et al. 2018), rabbits (Han et al. 2014; Kuroshima et al. 2015; Vandamme et al. 2007), rats (Yamamoto et al. 2014), and humans (Degidi et al. 2008; Mangano et al. 2017a), it was possible to observe mineralized tissues at the bone-implant interface in early and immediately loaded implants. Immediate loading allows immediate restoration of esthetics and functions, reduces the morbidity of a second surgical intervention, and facilitates the functional rehabilitation increasing patient acceptance and satisfaction (Degidi et al. 2010a). Functional loading, in experimental studies, appeared to stimulate bone apposition and accelerate implant osseointegration (Kuroshima et al. 2015). Mechanical loading increased osseointegration, bone volume, and bone mineral density; moreover, the quality of the peri-implant bone was changed with a higher quantity of osteocytes and a different alignment and degree of direction of the peri-implant bone collagen fibers (Kuroshima et al. 2015). Wolff stated that there was a direct link between mechanical loading and bone form; Wolff's law would imply that increased stresses acted as a stimulus to new bone formation, while reduced stress tended to produce bone loss (Traini et al. 2014). It is, however, necessary to proceed cautiously with the possibility of transferring to man the histologic results obtained in animal experimentation, due to the different loading conditions. Only few histological reports of clinically stable early or immediately loaded implants in man can be found in the literature (Degidi et al. 2003a, b, 2008; Di Stefano et al. 2006; Iezzi et al. 2009b; Mangano et al. 2017a; Romanos et al. 2005). Nowadays, the immediate loading treatment concept can be successfully used in implant dentistry. Immediate loading of endosseous oral implants is a well-established, evidence-based concept. There is some variance among the different studies with the exact definition of the term "immediate loading," as some research groups avoid occlusal contacts in the temporary restoration placed immediately after surgery. Other authors have demonstrated the use of an immediate placement procedure for restoring single teeth in the esthetic zone focusing on the stability of hard and soft tissues and recommended a careful elimination of all occlusal contacts after surgery (Degidi et al. 2009a). In MEDLINE, such concepts should be associated with "immediate restoration" or "immediate temporization" (immediate non-occlusal functional loading) and not with an immediate functional (occlusal) loading. To more accurately compare research findings, the term "immediate loading," in recent literature, should be used to indicate only implant-supported restorations with occlusal contacts in place immediately after implant surgery (Degidi et al. 2009b).

Loading Effects on Osseointegration

A submerged healing period of about 3–4 months has been thought to be necessary to obtain mineralized bone at the interface of dental implants, and an earlier implant loading has been reported to determine the occurrence of fibrous tissue at the bone-implant interface (Degidi et al. 2003a). An immediate loading protocol implies healing under loading and was thought to involve the risk of fibrous tissue encapsulation (Vandamme et al. 2008). On the other hand, several researchers have reported, in the last two decades, that in early and immediately loaded implants, placed in good quality bone, it was possible to obtain a high level of osseointegration, clinically and radiographically similar to that of implants used with a standard submerged protocol, and very high implant survival rates for immediately loaded implants have been reported in the literature (Eccellente et al. 2010) (Fig. 20a, b). Histologic comparisons have been reported in animal studies on implants that were immediately loaded versus implants with a delayed loading. The results of the BIC are variable with some papers showing more BIC, some less and some a similar value as the non-loaded side (Cesaretti et al. 2018; Quaranta et al. 2008; Sagirkaya et al. 2013). Albrektsson (2008), in a histological and histomorphometrical evaluation of more than 700 dental implants retrieved from man, found that unloaded, sleeping implants had a 10% lower BIC than the loaded implants. Piattelli et al. (1998) have histologically and histomorphometrically found a higher density in the bone around immediately loaded implants (screw-shaped, TPS-coated) in comparison to unloaded implants in the maxilla and mandible of *Macaca fascicularis*. According to this study, the histomorphometrical analysis demonstrated that in test implants, the BIC percentage was 67.3% in the maxilla vs. 73.2% in the mandible; in the unloaded implants, these percentages were 54.5% and 55.8%, respectively. Moreover, the bone around the immediately loaded implants tended to have a more compact appearance. The microstructure of the bone seems to be able to adapt to different loading forces (Kuroshima et al. 2015; Romanos 2015) (Fig. 21). Greater bone density was found when the implants were immediately loaded (Kuroshima et al. 2015; Romanos 2015), and mechanical forces seemed

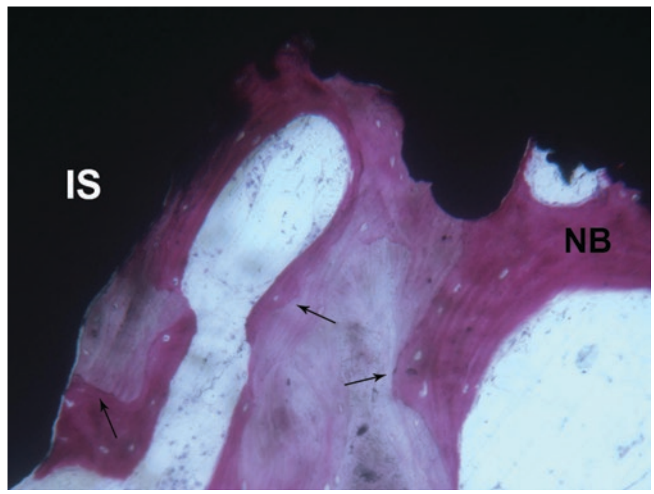

Fig. 21 Implant loaded for a very long period (30 years). Many remodeling areas (arrows) are present near the implant surface (IS), in direct contact with the metal. Bone formed in different time periods has different staining affinities (the bone formed more recently (NB) has a higher staining affinity for the dyes). (Acid fuchsin-toluidine blue 100X)

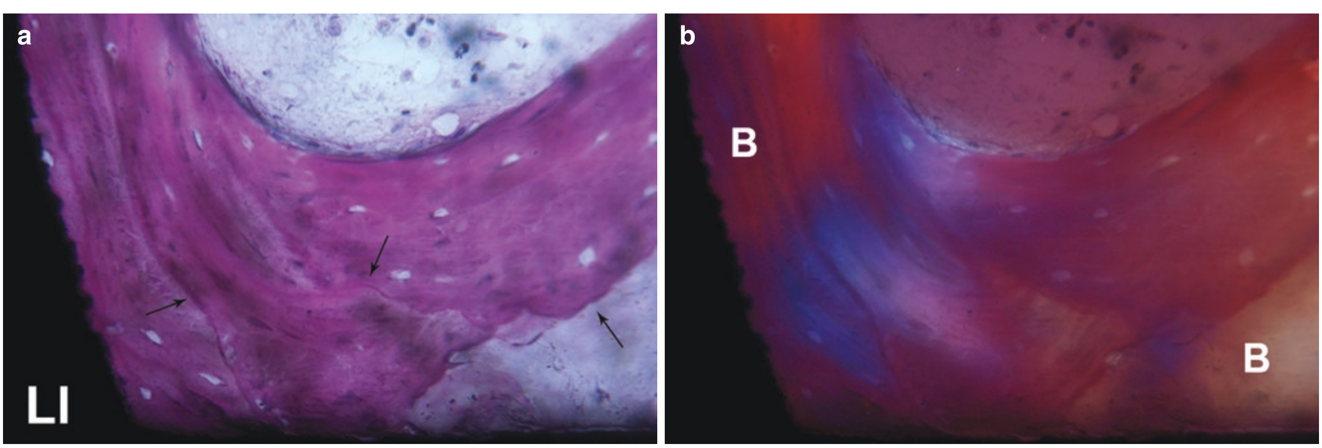

Fig. 20 (**a**) Around a loaded implant (LI), bone tissue shows different stages of maturation marked by reversal lines (arrows). (Acid fuchsin-toluidine blue 200X). (**b**) Polarized light microscopy image showing well-organized, lamellar bone (B) after many years of loading. (Acid fuchsin-toluidine blue 200X)

to be able to increase the mineral content of the bone by 34% with the formation of a dense lamellar bone in a peri-implant location (Romanos 2015). The density of the peri-implant bone and the BIC was found to be higher in loaded implants (Kuroshima et al. 2015; Romanos 2015). Yamamoto et al. (2014), in an experimental study in rat tibiae, found that bone metabolic activity was higher, during the period of wound healing, when load was applied. These authors also found that the peak of metabolism in immediately loaded implants was much lower than that found in delayed implants: this fact could mean that immediate loading of implants with a high primary stability might represent a much safer procedure than delayed early loading (Yamamoto et al. 2014). There are also histological and histomorphometrical reports showing similar levels of BIC percentages after immediate loading of oral implants with a progressive thread design, placed in the posterior part of the mandible of monkeys using different types of loading in comparison with delayed loaded implants (Quaranta et al. 2008). In contrast to the BIC levels, there is a higher bone density surrounding the immediately loaded implants than the density around implants loaded with the classical protocol (delayed loaded implants) in monkeys (Quaranta et al. 2008). The definition of osseointegration is clinical and is based mainly on implant stability. However, clinical stability alone is insufficient to demonstrate the presence of osseointegration, i.e., the presence of mineralized tissues at the interface with dental implants (Degidi et al. 2003a, 2007b; Iezzi et al. 2009b). Only the biopsy of human-retrieved implants allows a precise evaluation of the events occurring at the interface (Degidi et al. 2008, 2009a).

The range of BIC that is necessary for an implant to be osseointegrated is unknown (Iezzi et al. 2016; Romanos et al. 2005), and different values have been reported in the literature from as low as 25% to as high as 50% (Degidi et al. 2010b; Di Stefano et al. 2006; Scarano et al. 2006). Increased BIC may provide an earlier and better anchorage, thus allowing for an earlier functional loading of implants (Abrahamsson et al. 2004). Histological evidence of clinical successfully osseointegrated implants is rare in the literature, especially after a period of functional loading of more than 1 year (Coelho et al. 2009; Iezzi et al. 2016; Romanos et al. 2005; Uehara et al. 2004) because there are not many possibilities to get retrieved implants in humans. Removal and histological evaluation of implants due to fracture or other reasons (orthodontic, psychological, esthetic, hygienic) can give extremely important data, from the scientific point of view, as they could be useful to evaluate the healing events, thus the bone response, at the interface after different time periods (Uehara et al. 2004). Furthermore, such histological data demonstrate that different kinds of implant systems using various surfaces, inserted in different bone qualities in the maxilla or the mandible, can be equally successful in establishing osseointegration. Important factors in immediately loaded implants are primary stability, related to the thread design and the surface microstructuring, bone quality, and reduction of micromotion (i.e., splinting) (Romanos 2004).

Primary Stability

Good implant stability decreases the distortional strains in the newly forming tissues and improves the chances of neo-osteogenesis at the interface; on the contrary, a poor stability of the implants has been shown to determine an important distortional strain with fibrous tissue formation at the interface (Degidi et al. 2010c). A higher removal torque value (RTV) of dental implants might lead to a more predictable use of short implants and to a support of prosthesis with a smaller number of implants and allows shorter healing periods (Degidi et al. 2007a).

Macro-/Microstructure

An implant should have a retentive shape. Over the years, many different types of implants have been proposed and used, i.e., blades, screws, and root-form implants. Screws seem to behave in a better mechanical way than cylindrical implants without threads (Romanos 2015).

Blades

In blade implants, a high failure rate was reported due to their non-retentive shape (Fig. 22). This has been attributed to the formation of connective tissues around their surface

Fig. 22 A retrieved blade partially surrounded by hard tissues

(Proussaefs et al. 2002). Although the presence of mineralized tissues at the interface with blade implants has been reported (Di Stefano et al. 2006; Proussaefs et al. 2002), the view that blade implants cannot integrate still persists (Proussaefs et al. 2002). Blades are the immediately loaded implants with the longest clinical history, so their histological evaluation has a historical value and may certainly have some applications to root-form implants (Proussaefs et al. 2002) (Fig. 23). In blade implants retrieved after 13 and 21 years of function, mature bone in tight contact with the implant surface was seen around most of the implant surface (Proussaefs et al. 2002). The response of the bone tissue appeared not to be disturbed by the stresses and strains transmitted at the interface.

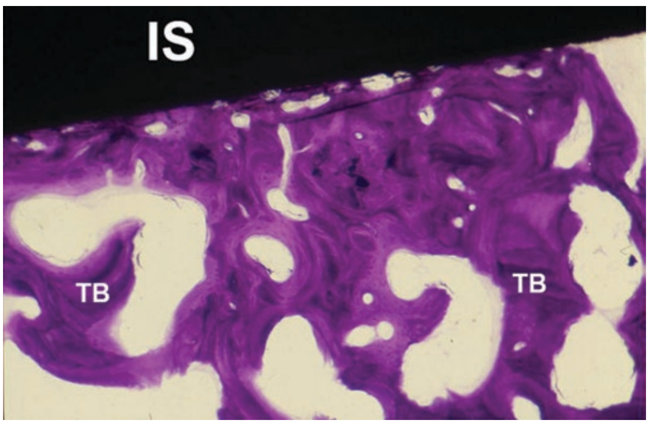

Fig. 23 Trabecular bone (TB) at the interface with the implant surface (IS) in a blade retrieved after about 20 years of loading. (Acid fuchsin-toluidine blue 40X)

Screws

The screw has a large mechanical retention and greater ability to transfer compressive forces to the peri-implant osseous tissue and to produce lower shear stresses at the interface (Gapski et al. 2003). Screw design not only minimizes micromotion of the implant, but also makes a significant contribution to the initial stability of the implant during placement (Steigenga et al. 2004); therefore threaded implants present considerable advantages compared with press-fit implants for the immediate loading protocol. Macroretention offered by implant thread can reduce the risk of implant movements in the case of immediately loaded implants. Additionally, the threads increase the surface area of the implant (Gapski et al. 2003). In the early stages of healing, many blood vessels were observed within the threads (Fig. 24a, b), as well as new bone formation was appreciated few weeks after the implant insertion (Fig. 25). In conclusion, threads are also used to maximize the initial contact, improve the initial stability, enlarge the implant surface area, and favor dissipation of interfacial stresses (Steigenga et al. 2004). A high quantity of mineralized tissue was found in an immediately loaded screw, retrieved after several years of function (Iezzi et al. 2009b).

Root-Form Implants

Very high success and survival rates have been reported in immediately loaded dental root-form implants (Degidi et al. 2003c; Proussaefs and Lozada 2004), and immediately

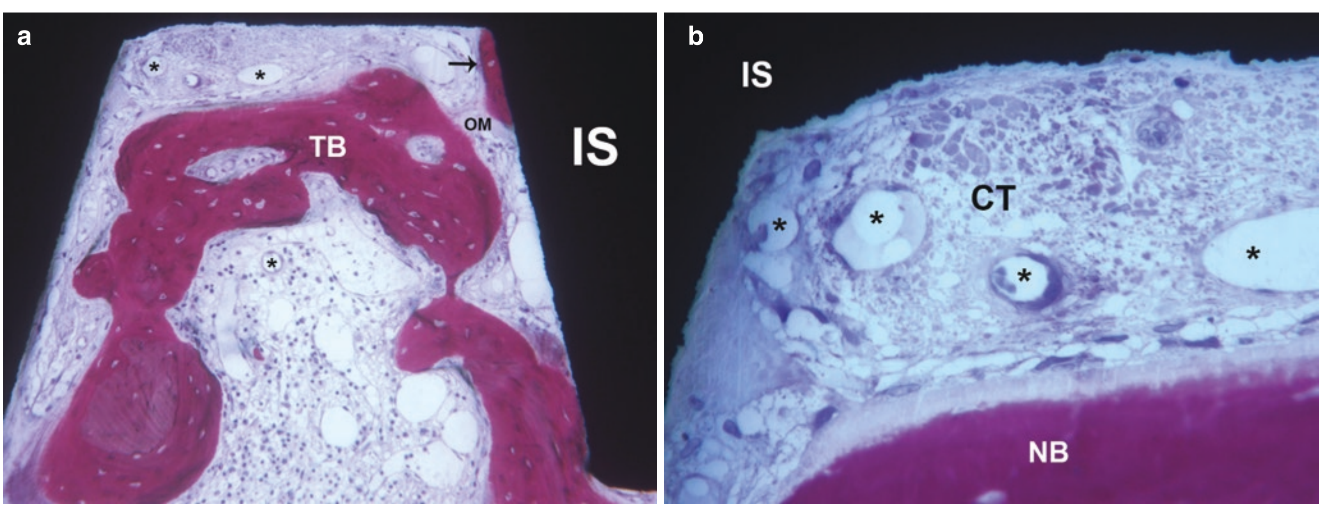

Fig. 24 (**a**) Intense angiogenic (*) and osteogenic activities are evident. Only a small bone trabecula (arrow) can be seen in contact with the implant surface (IS) and connecting through a bridge of osteoid matrix (OM) to the trabecular bone (TB). (Acid fuchsin-toluidine blue 100X). (**b**) High-power image showing dense connective tissue (CT) and newly formed blood vessels (*) between the implant surface (IS) and the newly formed bone (NB). (Acid fuchsin-toluidine blue 400X)

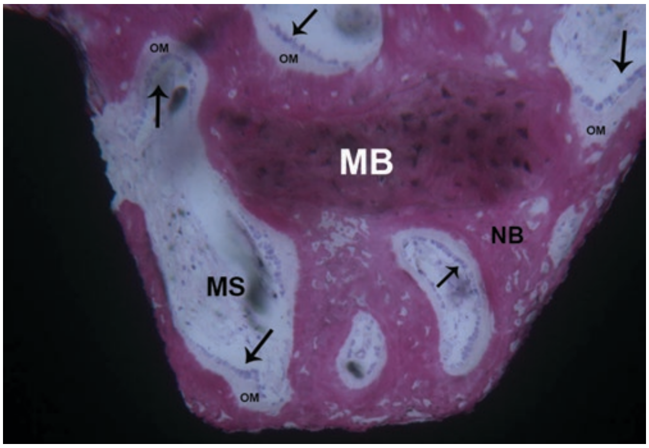

Fig. 25 Contact osteogenesis with still active osteoblasts (arrows) producing osteoid matrix (OM) inside the marrow spaces (MS). The newly formed bone (NB) shows wide osteocyte lacunae also in the vicinity of the metal surface. Only a small portion of mature bone (MB) incorporated into the newly formed one is present. (Acid fuchsin-toluidine blue 100X)

loaded implants have shown a clinical long-term predictability similar to those of conventionally loaded implants (Gapski et al. 2003). Implants with a rough surface have been shown to achieve clinical osseointegration and prosthetic predictability after 2 months, even when placed in soft bone. Surface texture has an influence on the quantity and quality of bone remodeling at the interface. It is also important in determining the pattern of healing under loading, especially in particularly demanding situations such as immediate loading. Implants with a sandblasted and acid-etched (SLA) surface were introduced to the market with a protocol calling for loading after 6 weeks under standard bone conditions (Salvi et al. 2004). In a study by Degidi et al. (2003b), no macroscopic differences were apparent between implants with a sandblasted and acid-etched surface and implants with a titanium plasma-sprayed surface. The authors used three implants with different designs: the only significant difference between them was that a higher crestal vertical bone resorption was observed around the epithesis implants which were not threaded.

Bone Quality

There is a need to investigate the bone healing processes at the interface, especially concerning the question of which type of bone response is present around immediately loaded implants inserted in poor quality bone (Degidi et al. 2010c; Mangano et al. 2017 a, b). An analysis of human biopsies of immediately loaded implants is the best way to ascertain the quality and quantity of the peri-implant hard tissues (Romanos et al. 2005). Rocci et al. (2003) reported very high BIC (84.2%) with apparent undisturbed healing in implants that had been inserted in bone quality sites 3 or 4 and that had been biomechanically challenged. The histological data obtained from a study by Degidi et al. (2008) confirm that immediate loading did not have an adverse effect on osseointegration. However, in areas with poor bone quality, there are not many current clinical prospective, randomized, well-controlled studies, proving the application of immediate loading as an alternative treatment concept in daily practice.

Reduction of Micromotion

It has been shown that the occurrence of mineralized tissue at the interface is mainly related to the biomechanical stability of the implant and to the amount of micromotion. The biomechanical response of the bone during loading is dependent on the implant shape (cylindrical, tapered) as well as the thread geometry interfacing with different bone qualities. It has been reported that controlled implant micromotion had a positive effect on the bone formation at the interface (Vandamme et al. 2007). The threshold of critical micromotion appears to be comprised between 50 and 150 μm (Gapski et al. 2003). Other ways to increase the possibility of a rigid fixation are the use of different surface features, like a porous coating; the use of plasma spray, sand-blasting, or bioactive coatings; and the use of an implant with a retentive shape (i.e., a screw-shaped implant) (Steigenga et al. 2004). Also the splinting of immediately loaded implants may be useful in providing a sufficient degree of stability and a protection of the bone-implant interface from the detrimental effects of overloading. Rigid splinting with minimal lateral forces decreases the amount of micromotion during the early healing phase, giving the implant a higher tolerance to deleterious micromotion. In addition, implants splinted together may decrease the risk of overload to each implant as a result of greater surface and improved biomechanical distribution (Cesaretti et al. 2018).

Advantages of Immediate Loading

Immediate loading can allow a reduced treatment period in the edentulous patients (Linkow and Miller 2004). With two-stage implants, there is a delay in the final rehabilitation and the difficulty of wearing a conventional denture during the healing period. Also the immediate psychological benefit for the patient must be considered (Erkapers et al. 2011). Immediate loading fulfills the patient desire to have new teeth as soon as possible for esthetic and functional reasons (Erkapers et al. 2011). It determines a reduction of the oral handicap and decreases the total treatment time with increased patient satisfaction, decreased patient anxiety and discomfort, better function and esthetics, and avoidance of a conventional denture during the healing period (Degidi et al. 2009a, 2010a). When primary stability is achieved, and a proper prosthetic treatment plan is followed, immediate loading is a feasible concept (Gapski et al. 2003). Romanos reports (2015) that immediate loading improves bone regeneration and improves bone remodeling at the bone interface.

Criteria for the Evaluation of Immediate Loading Success

From a scientific point of view, the tissue integration of dental implants can be considered successful only if the bone-implant interface is maintained in the long term and if mineralized tissue is present and remains at the interface with the implants. The bone is strongest in compression and weakest in shear loading (Han et al. 2014). Compressive force transfer would decrease the microstrain to bone, in comparison to shear forces type transfers (Coelho et al. 2009). The higher the microstrain, the higher the bone turnover rate. This results in a more reactive bone, which is weaker and has a lower modulus of elasticity (Coelho et al. 2009). Han et al. (2014), in a finite elements rabbit study on immediately loaded implants, found that the stress concentrated in the outer marginal bone and that, as osseointegration progressed, the stresses on the peri-implant bone tended to decrease; the higher was the BIC, the more homogeneous were the stresses on the peri-implant bone, and the lower were the stress magnitude on the bone.

According to the literature, an osseointegrated, clinically stable, thus successful implant is associated with a BIC of at least 25% (Iezzi et al. 2016; Mangano et al. 2015). This is dependent on the implant form, the surgical procedure used, the type of the loading forces, and the loading period. In general, the measured direct bone-implant contact was on average 84.9% around retrieved implants placed 6 months to 16 years period (Degidi et al. 2010b; Di Stefano et al. 2006; Scarano et al. 2006). BICs around implants loaded up to 1 year were 56.5% and were increased after a longer loading period (mean value about 66%) (Degidi et al. 2010b; Di Stefano et al. 2006; Scarano et al. 2006).

Concluding Remarks

Early and immediately loaded dental implants retrieved from human jaws presented a moderate to higher BIC% depending on the bone density and implant surface topography. In addition, local and systemic factors could also impact not only on the bone behavior around these implants but also on the long-term follow-up. However, the influence of occlusal loading and the axis of this force as well as the material of the implant-supported restoration must be evaluated in both preclinical studies and RCTs.

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Biomechanics and Occlusion in Immediate Loading

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Take-Home Messages

- The lowering of tensions is one of our aims when planning cases for immediate loading, since we know the complications they can cause. It is therefore necessary to reduce the incident forces or increase the surface upon which they fall.
- Increasing the number of implants is the most effective method for improving surface area and reducing stress and for shortening the duration of symptoms and the risk of overhangs.
- Implant macrogeometry could improve the transmission of these forces, and in immediate loading protocols this may even prove more significant than an increase in width. The number and depth of the threads exert an influence, since they determine an increased implant-bone contact surface and favor primary stability.
- Internal connections offer greater stability at the implant-prosthesis interface, reducing the possibility of micro-movements during loading.
- The absence of passive adjustment of the prosthesis can be associated to mechanical complications such as loosening or fracture of the screws and fracture of the superstructure, though its association to biological complications such as marginal bone loss and the loss of osseointegration cannot be confirmed.
- Narrow occlusal surfaces reduce the generated stress.

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Introduction

Biomechanics is understood as the response of biological tissues to the loads applied to them and is studied using the means and methods of mechanical engineering applied to the relationships between live forces and structures. Biomechanics in implantology is determined by the impact which loads and deformations produce upon the implant-prosthesis system and stomatognathic system as a result of the action of functional and parafunctional forces. What is this? What should be done? How does it apply to dental prostheses?

We must remember that biomechanical behavior of dental implant differs of tooth, because there is no periodontal ligament in the implant-bone interface, so many rules that usually are employed in dental-supported prosthesis were not useful in implant prosthodontics.

In implantology, the implant-prosthesis system is exposed to very important stresses, and many complications can arise from such stresses. For example, the loosening and/or fracture of screws is recorded as the most frequent complication in unitary implants and is more prevalent in external than in internal connections. Such loosening is the weakest link in the chain and constitutes the first manifestation in the event of stress situations; the final consequence may be fracture of the screw. Alternatively, the coating material or frame of the prosthesis itself may experience fracture (Figs. 1a–d).

We must review the biomechanical balance in such situations of alarm. In this regard, static loads may be subjecting the screwed system to constant tension (e.g., lack of passive adjustment), or dynamic loads may overburden the system (e.g., parafunctions or unwanted occlusal contacts). These aspects take on even greater relevance when performing immediate loading procedures, since in such scenarios osseointegration of the implant with the bone has not yet been achieved (Figs. 2a–l).

If implant loading is well distributed, correct osseointegration will be established. However, this relationship is very

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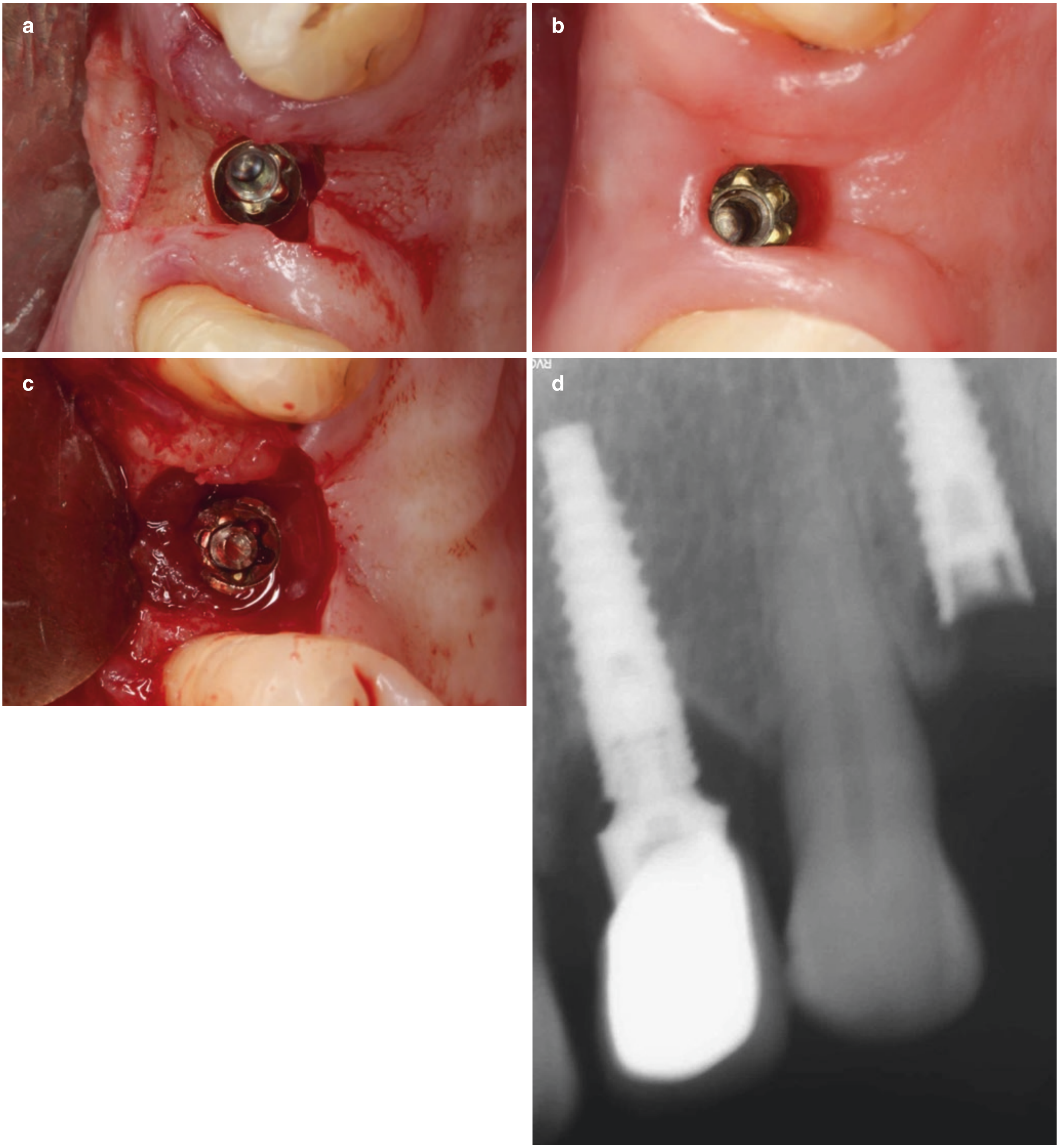

Fig. 1 (**a**) Surgical image of Phibo® Aurea NP implant placed at 2.4 position (Phibo Aurea®, Phibo Dental Solutions, Sentmenat, Barcelona, España). (**b**) Keratinized mucosa after osseointegration period. (**c**) Screw fracture and buccal bone loss by peri-implant infection, provoked by continued stress on CAD/CAM single-tooth fixed prosthesis connected to implant-prosthetic abutment. (**d**) Periapical radiograph after fracture of both prosthetic screw and implant connection

delicate (Berglundh et al. 2005), since a number of factors such as premature contacts, occlusal interferences, poorly designed prostheses, non-ideal positioning of the implant, and parafunctional habits can contribute to "occlusal overload" of the implant and produce irreversible structural and biological damage. This occurs due to a lack of adaptation of the tissues to the excessive forces applied to the implant, resulting in force transmission to the implant-bone interface.

Micro-movements at the bone-implant interface during the osseointegration period can be tolerated to a certain point. The literature recommends that such movements should not exceed 150 μm. Exceeding these limits could induce the formation of fibrous tissue at the bone-implant

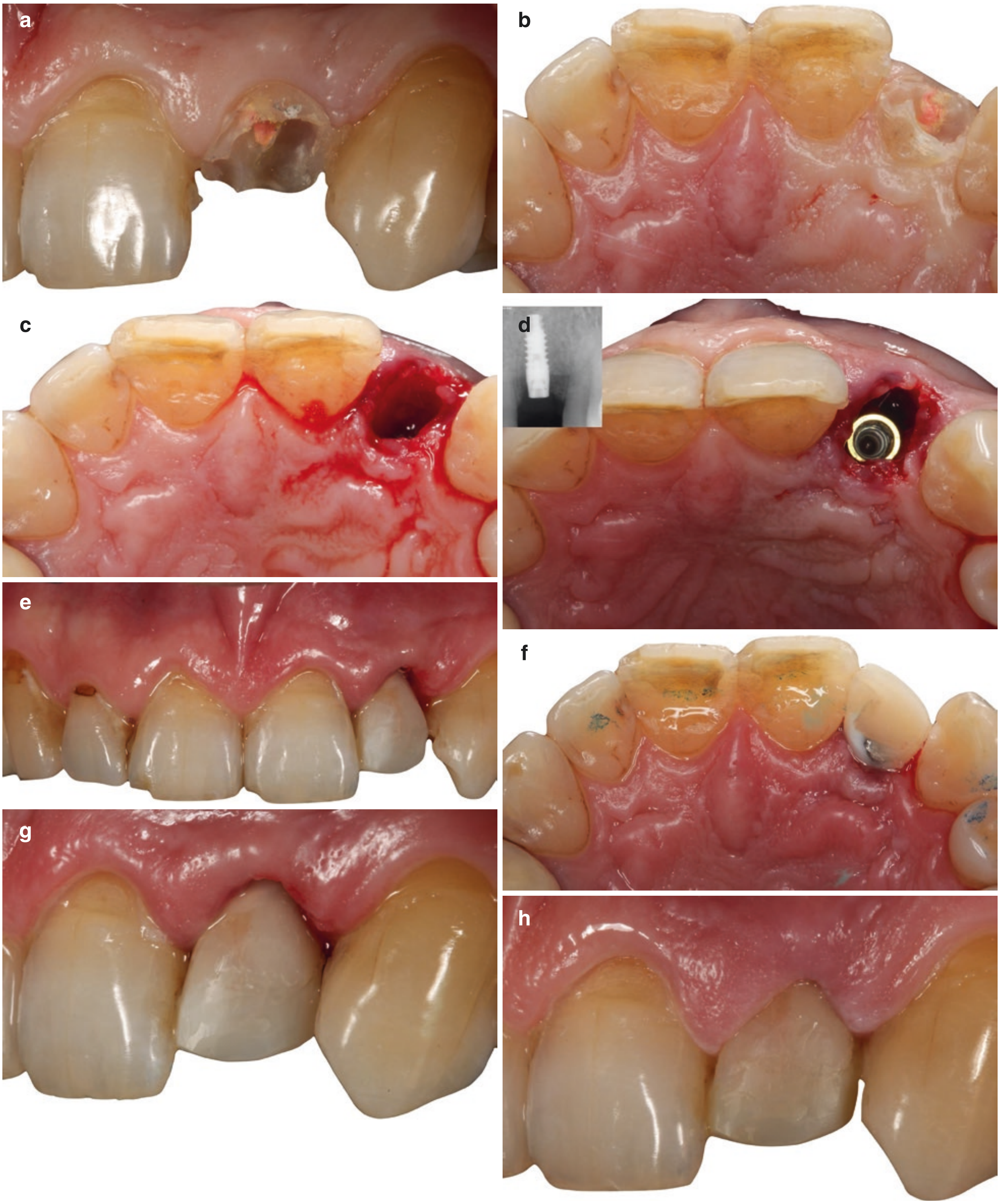

Fig. 2 (**a**) Initial presurgical frontal view of fractured upper left lateral incisive at juxta gingival level, without chance of conservative treatment. (**b**) Occlusal view of radicular remnant. (**c**) Occlusal view of socket after radicular remnant extraction. (**d**) Post-extraction tissue-level dental implant placement (PRAMA®, Sweden & Martina, Due Carrare, Italy). (**e**) Screwed immediate loading crown connected to implant internal connection. (**f**) Occlusal adjustment of immediate restoration. The patient presents bruxism. Thus, to avoid postoperative complications, there is not any occlusal contact in provisional crown. (**g**) Postoperative frontal view of immediate loading restoration. (**h**) Frontal view of immediate loading restoration after 1 week. (**i**) The patient come after 1 month presenting mobility of implant crown and implant failure without peri-implant infection. After inflammatory tissue debridement, a new implant is placed following two-surgical phase protocol for its rehabilitation without immediate loading. (**j**) Partial-thickness flap sutured associated to subepithelial connective tissue graft placement on buccal side to avoid the bone ridge collapse. (**k**) Cement-retained metal-ceramic crown placement after 3 months of implant healing. (**l**) Frontal view of upper left lateral incisive after 3 months of prosthetic loading

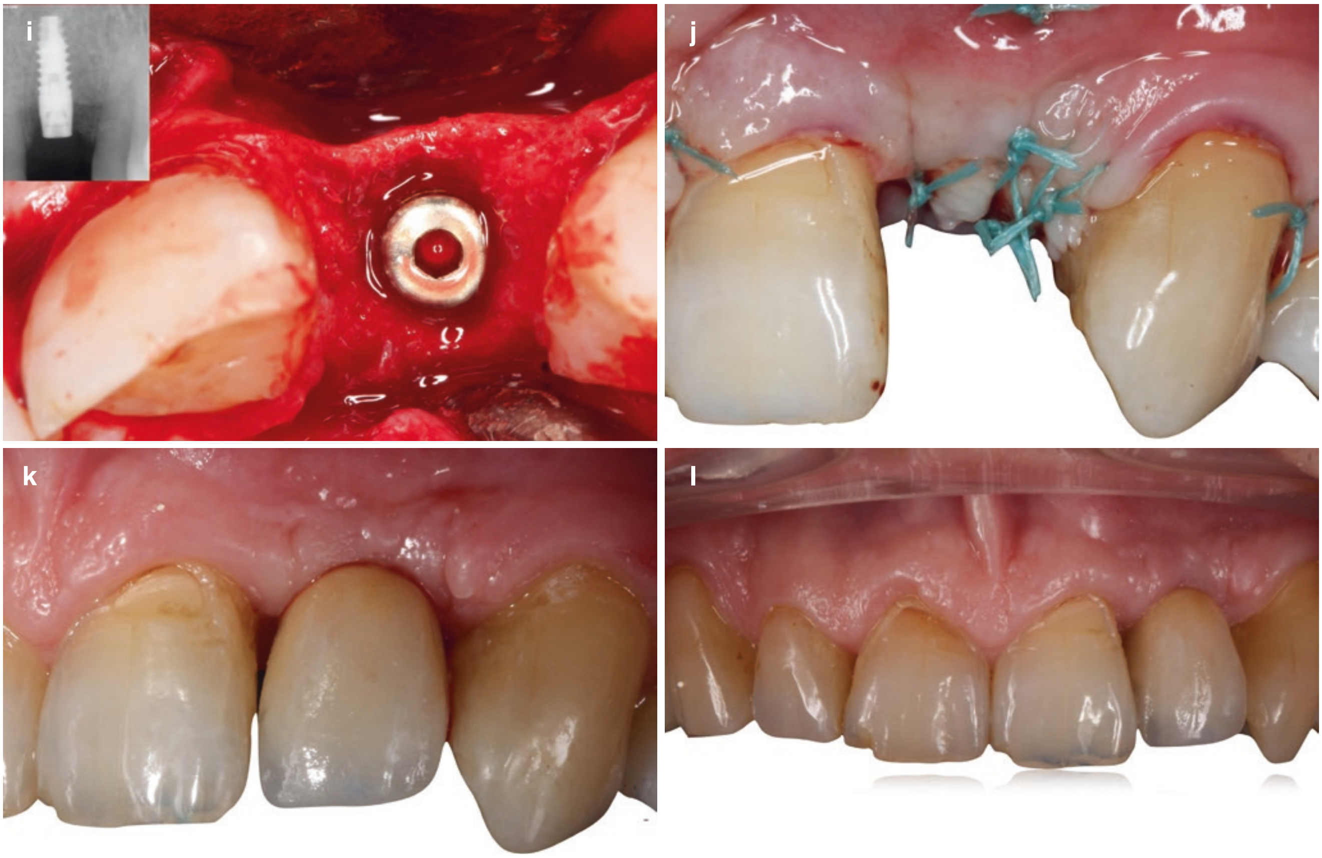

Fig. 2 (continued)

interface and therefore cause osseointegration failure (Lekholm et al. 1985; Szmukler-Moncler et al. 1998). Therefore, in order to guarantee the osseointegration of immediate loading implants, it is essential to achieve good primary stability, ensuring that the implant-prosthetic design minimizes micro-movements during the osseointegration process (Aparicio et al. 2003). Such micro-movements constitute the response of the implant—prosthesis—bone complex to the forces and tensions of the stomatognathic system (Fig. 3).

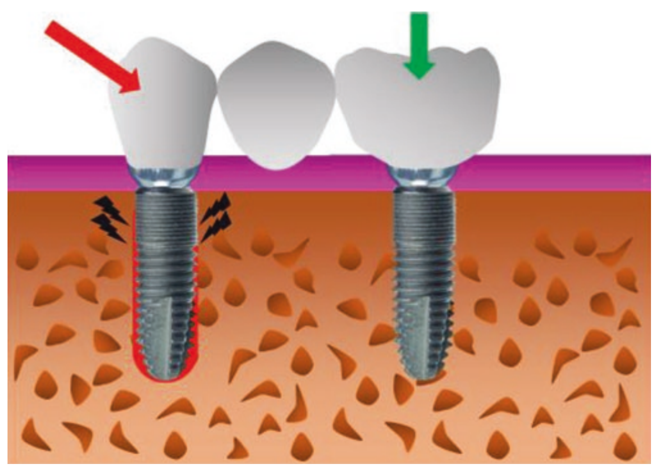

Fig. 3 The lack of control of the forces during the osseointegration period generates fibrous tissue at the implant-bone interface (Ticare Inhex®, Mozo-Grau, Valladolid, Spain)

Biomechanical Concepts

Tension

Tension, or pressure, is the applied force per unit area:

$$\text{Tension} = \frac{\text{Force}}{\text{Area}}$$

One of our aims in planning cases for immediate loading is to reduce tensions, since we know the complications they can cause. It is therefore necessary to reduce the incident forces or increase the surface upon which they fall.

Force

Force is defined as any action or influence capable of modifying the state of motion or rest of a body or of deforming it. The forces could be of compression, traction, and torsion.

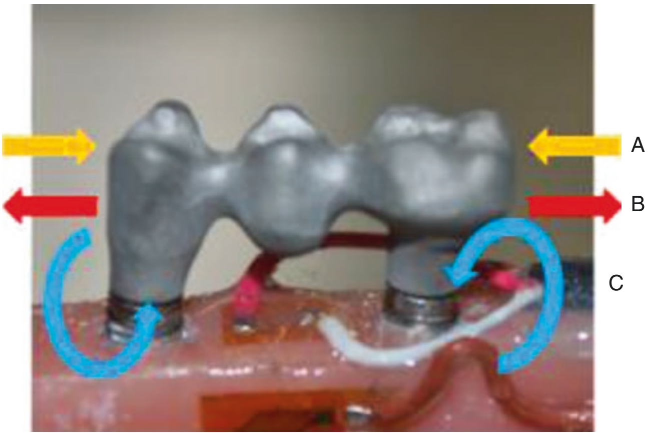

Fig. 4 Incident forces in the implant-prosthesis complex. (**a**) Compression. (**b**) Traction. (**c**) Torsion

Forces of Compression, Traction, and Torsion

Compression forces push masses together; tensile forces separate them; and torque causes the implant to slide (Fig. 4). The cortical bone is more resistant to compression and weaker to torsion forces.

Biomecanichs of the occlusal forces applied to oral implantology

The vector components of the occlusal forces affect the micro-movements of the implant. Finite element analysis shows that the application of oblique or lateral forces results in greater stress in the marginal bone (Goiato et al. 2014).

Many studies have reported no increased failure rate or marginal bone alterations in implants with excessive lateral loads (Goiato et al. 2015). The clinical study carried out by Aparicio et al. (2001) recorded no significant differences in bone loss (Aparicio et al. 2001). Koutouzis and Wennström (2007) in turn recorded changes in the marginal bone around straight (0–4°) and angulated implants (11–30°) over 5 years of follow-up but observed no relationship between implant angulation and bone loss (Koutouzis and Wennström 2007).

The forces acting upon the bone produce a deforming effect upon the latter called tension. The resistance to this tension on the part of the intermolecular bonds in bone tissue is referred to as stress. According to the *Glossary of Oral and Maxillofacial Implants* (Laney 2007), occlusal overload is the "application of the occlusal load by function or parafunction, in excess, beyond what the implant component, the osseointegrated interface or the prosthesis are able to withstand" and constitutes the main cause of biomechanical complications of implants (Koutouzis and Wennström 2007).

Experimental studies in animals (Vandamme et al. 2007a, b; Duyck et al. 2006) indicate that overloading compromises the establishment of osseointegration of the implant in immediate loading procedures, producing marginal bone loss. This corroborates the importance of securing sufficient primary stability and control of forces in relation to implant prognosis. The greater the amount of applied stress, the greater the difference in bending between the implant and bone. When stress increases, the implant has a lesser probability of osseointegration, and the probability of fibrous tissue growth increases.

Static and Dynamic Loads

Two kinds of loads-static and dynamic-act upon the implant-prosthesis system. Static loading has been defined as the resultant of the forces applied on the implant-prosthesis-bone complex before applying any type of occlusal load and is represented by preloading of the prosthetic screw and the absence of passive adjustment. Dynamic loading in turn refers to the resultant of the forces to which the complex is subjected during masticatory function. Occlusal overload is similar to uncontrolled dynamic loading.

Jemt and Lekholm (1998), in an animal study, explored the effect upon the bone of overloading in implants with unadjusted prosthetic structures. The stresses generated as result of inadequate passive adjustment (static load) were greater on the prosthetic junctions than on the implant-bone interface. Significant imbalances of the implant-abutment system create displacements and loosening of the components of the prosthesis and even implant fracture but have few effects upon the peri-implant bone (Katsoulis et al. 2017). However, a misfit in implant-abutment system could be a factor that may contribute to the peri-implant bone remodeling; it is occasionally observed when an implant-supported prosthesis is inserted (Jemt and Lekholm 1998).

Biomechanical Factors

Type of Bone

The type of bone often influences treatment outcome. There are variations in biomechanical behavior between the four types of bone, influencing the ability of the bone to receive physiological loads. Poor bone quality leads to a reduction of compact bone and a lack of primary stability of the implant—such stability being necessary to perform immediate loading. An increased initial bone density not only provides greater primary stability during the osseointegration process but also allows better distribution and transmission of forces to the bone-implant interface.

The percentage of bone contact is significantly greater in cortical bone than in trabecular bone. In order to reduce stress in low-density bone, some authors recommend the placement of a larger number of implants or the use of implant designs with a greater contact surface.

Design of the Implant

In attempting to increase the surface distribution of loads, increasing the size of the implant can be considered. In this regard, implant width is more important in relation to stress distribution than length once initial fixation and torque resistance have been established (Goiato et al. 2014). Length is an important factor for securing good primary stability of the implant and is important for immediate and early loading protocols. It has been found that only the most coronal 6–7 mm of the implant supports all the tensional load of the system (Samira and Sinan 2010; Han et al. 2016).

Implant macrogeometry could improve the transmission of these forces, and in immediate loading protocols this may even prove more significant than an increase in width. The number and depth of the threads exert an influence, since they determine an increased implant-bone contact surface and favor primary stability.

A smaller than usual thread design in the cervical area allows greater axial loads to be assimilated, improves axial load distribution, and reduces stress compared to implants with machined cervical designs (Niu et al. 2017).

Platform Switching

The platform-switch concept, introduced by Lazzara and Porter (2006), consists of the use of prosthetic components of smaller diameter with respect to the diameter of the implant platform. Many studies have reported a reduction in marginal bone resorption when platform switching is performed (Fig. 5).

Thanks to the study of models based on finite elements, it is presently believed that the implementation of a modified platform can reduce the stress generated the in peri-implant bone. Tabata et al. (2011), in a finite element study comparing regular, reduced, and increased diameter platforms, observed less stress in the peri-implant bone and in the implants when a modified platform was used (Tabata et al. 2011).

Connection Type

The maintenance of sealing of the implant-prosthesis interface can be influenced by the geometric design of the implant connection. Considering two large groups of implant-abutment connections, a distinction can be made between internal connections and external connections. Internal connections offer greater stability of the implant-prosthesis interface, reducing the possibility of micro-movements during loading. Experimental studies have reported superior behavior against static and dynamic loads when internal connections are used (Gracis et al. 2012) (Fig. 6).

In a recent study, Ribeiro et al. (2011) evaluated fatigue resistance in three types of abutments with different connec-

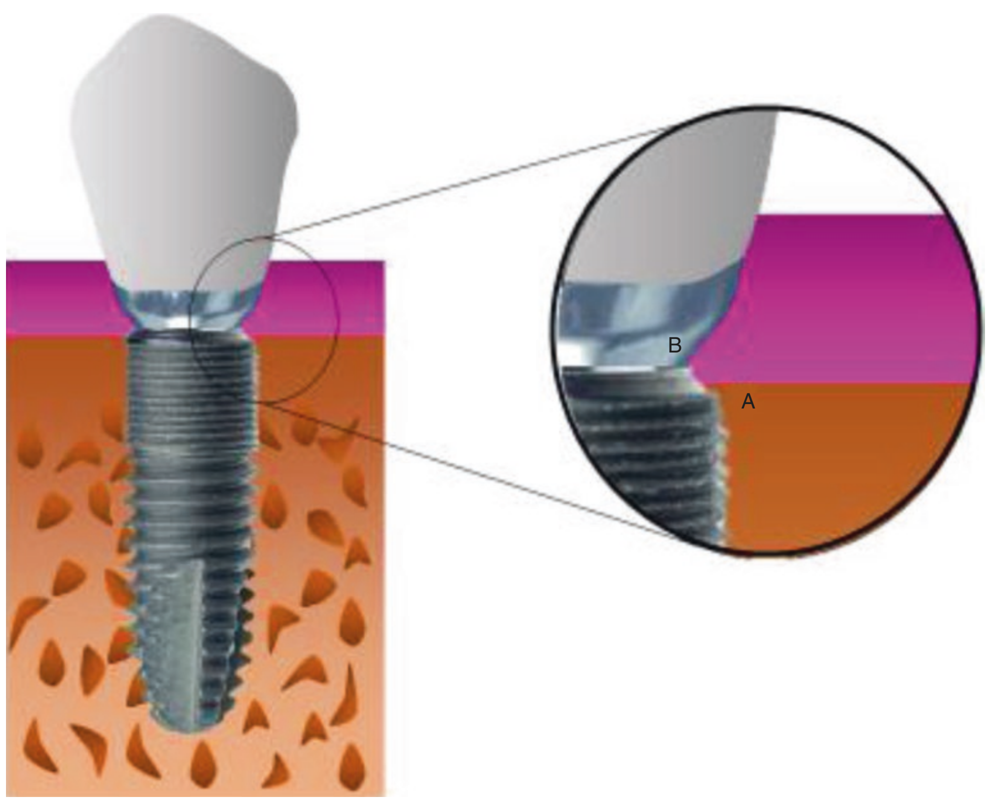

Fig. 5 Concept of platform switching. (**a**) Implant platform. (**b**) Prosthetic abutment (Ticare Inhex®, Mozo-Grau, Valladolid, Spain)

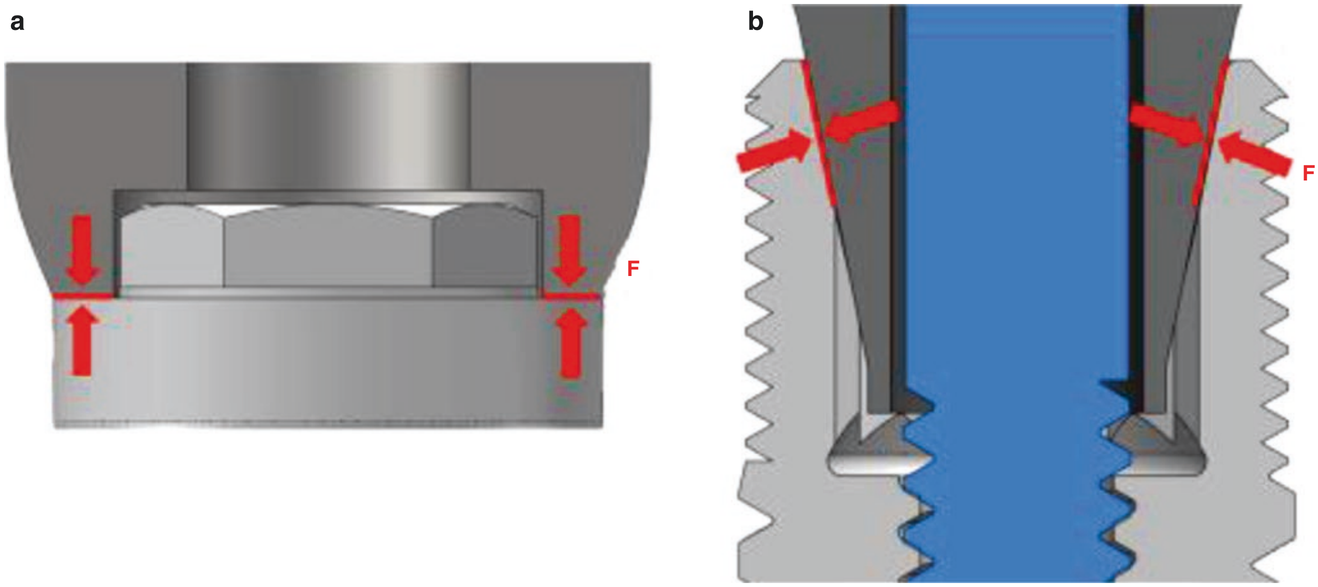

Fig. 6 Junctional forces (F) in external connection (**a**) versus internal connection (**b**). Note the greater amount of force in the internal connection versus the external connection. Courtesy of Ticare® (Mozo-Grau, Valladolid, Spain)

tions (external hexagon, internal hexagon, and Morse taper), analyzing the fracture point of the screw. The resistance to fracture was lower in external hexagonal connection pillars, with no significant differences being observed between the internal hexagon and Morse taper designs. Eighty percent of the screw fractures occurred in the threaded part, while the rest presented damage to the thread but no fracture. This connection can also be influenced by factors such as adjustment of the components, machining precision, contamination with the saliva, and preloading of the screw (Ribeiro et al. 2011).

Crown-Implant Ratio

Historically, the optimum tooth-crown ratio in natural teeth was established as 0.5:1, with 1:1 representing the clinically accepted limit. In implants, it is considered that there is a 20% increase in the forces generated per millimeter in height of the crown; therefore, an increase in the crown-implant ratio creates important leverage in the implant and surrounding bone when lateral forces are generated. The occlusal forces transmitted on the axial axis of the implant are not influenced by an increase in the height of the crown. However, completely axial forces are only exceptionally produced on the implant.

No relationship has been established between crown-implant size and marginal bone loss in unitary implants when lateral forces are exerted (Garaicoa-Pazmiño et al. 2014). Nevertheless, it is accepted that an increase in crown-implant ratio is potentially harmful to the prosthetic components, as there is a significant increase in the loosening and fracture of prosthetic abutments (Urdaneta et al. 2010). This biomechanical complication makes it advisable to splint short implants.

Passive Fit

Passive adjustment can be defined as the relationship or connection between two materials, which once established does not produce tensions in either material. Even today, consensus is lacking as to what would be the tolerable discrepancy of a structure over several implants.

While the importance of passive adjustment with the superstructure of the implant is still a matter of debate, it is true that the literature describes poor fitting of the prosthesis to be associated with mechanical complications such as loosening or fracture of the screws and fracture of the superstructure—though its association to biological complications such as marginal bone loss and loss of osseointegration has not been confirmed (Katsoulis et al. 2017). A schematic representation of passive adjustment is provided in Fig. 7.

Keys for Biomechanical Control

Increase the Number of Implants

When the specific situation requiring treatment causes the tensions and therefore the forces acting upon the implant-prosthesis system to increase due to circumstances beyond our control (replacement of a canine, low bone quality,

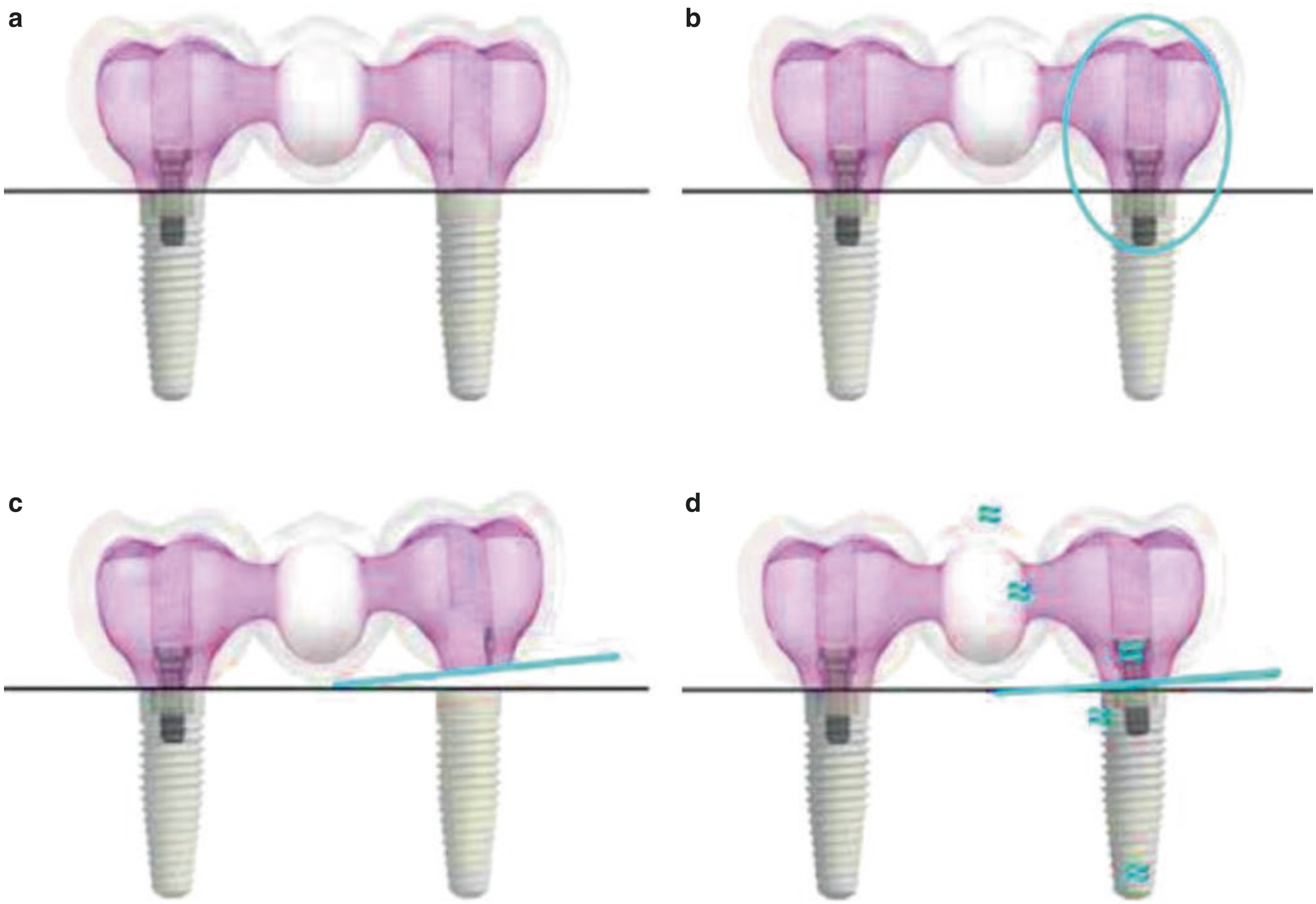

Fig. 7 Schematic illustration of a screw-retained implant-supported fixed denture (IFD) and the two related implants. The perfectly fitting IFD shows passive fit in the one-screw test (**a**) and in the final position with all screws tightened. (**b**) The ill-fitting IFD shows a certain gap at the interface in the one-screw test, (**c**) and in the final position a non-passive fit is noted with strains in the components (screw, framework, veneer, implant, bone), together with a remaining micro-gap at the interface (**d**). Image adapted from Katsoulis et al. (2017)

porcelain antagonist, etc.), we must try to compensate the excess tensions by increasing the surface over which they are distributed. Increasing the number of implants is the most effective way to increase the surface area and thus reduce stress—this being particularly relevant when rehabilitating posterior sectors. Increasing the number of implants decreases the pontics and therefore the non-axial stresses they generate.

Pontic Length Reduction

When rehabilitating with fixed prostheses on natural teeth, we seek to avoid very long pontics. Rehabilitation with prostheses on implants follows this same principle. When biting, a force is exerted on the pontic that causes it to flex. In the case of a bridge over natural teeth, some flexion of the pontic is absorbed by the periodontal ligament of the abutment teeth. This does not occur in the case of bridges over implants lacking such a ligament and with no intrusion capability. The greater the distance between the abutments, the greater the flexibility of the prosthesis material. The greater the load, the greater the bending effect. This bending of the metal causes shear loads and tension on the abutments (Fig. 8). The greater the flexion, the greater the risk of problems at prosthetic component level.

In an ideal treatment plan, the size of the pontics should be limited to the size of two premolars (between 13.5 and 16 mm). If necessary, we can increase the number of implants to reduce the length of the pontic and thus the generated stresses.

Splinting

Another way to increase the distribution surface of the loads is through splinting (Al Amri and Kellesarian 2017). The criteria for individualizing or splinting teeth-supported prosthesis are not applicable to implants. This is even more so in the case of immediate implant loading procedures, where

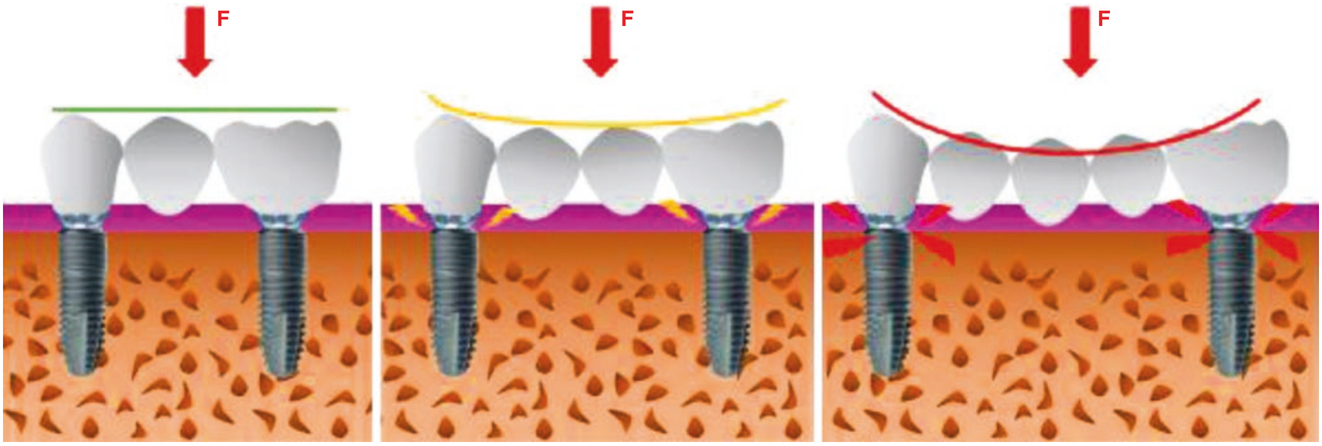

Fig. 8 The greater the distance between the abutments, the greater the flexibility of the prosthetic material. The higher the load, the greater the flexion

osseointegration has not yet been achieved and the control of micro-movements is crucial, as already commented. Therefore, splinting of the implants for immediate loading procedures in totally edentulous and partially edentulous patients with multiple replacements is mandatory.

Splinting has a series of mechanical and prosthetic advantages:

- Better distribution of forces, since the surface on which they act is increased.
- Possibility of overhangs. Avoiding them in immediate loading procedures will be commented below. However, in certain situations where implant placement in terminal positions is not possible because of surgical limitations, securing good control of the rest of forces may allow us to place a cantilevered piece splinting several implants.
- Splinting facilitates laboratory procedures, since there is no need to reach a point of contact.

Distal Cantilever Reduction

Cantilevers act as magnifiers of forces upon implants, abutment screws, cemented or screwed prostheses, and the implant-bone interface, thereby compromising implant osseointegration.

If a single implant does not have a cantilever, a force of 100 N applied directly onto it results in a compressive force of 100 N that poses no problems. However, in the presence of a 1-cm cantilever, that same force of 100 N becomes a 100 N lever force or torque of 100 N. Likewise, a 2-cm cantilever results in 200 N of torque. Taking into account that the torque to which the abutment screw was tightened is 30 N, the system is exposed to unfavorable loads (Fig. 9).

More recent studies such as that published by Goiato et al. (2016) confirm these data by means of photoelastic analyses of different models that compare different connection systems (external and internal) with different cantilever lengths (one or two coronary units) subjected to 100 N forces in oblique axial directions of 45°. The authors concluded that the type of prosthetic connection does not directly influence stress distribution in the case of axial loading. In contrast, the length of the overhang did have a direct influence upon stress distribution. The models with two cantilevered crowns showed more stress, with greater force concentration in the cervical part of the implant (Goiato et al. 2016).

The term “angled implants” refers to implants placed with an inclination of 25° or more with respect to those placed axially. According to some authors, the placement of angled implants in the posterior sector offers a series of advantages over axial implants, allowing a reduction of the extension of the distal cantilevers and improving distribution of the loads in the prosthetic superstructure.

Zampelis et al. (2008), in a two-dimensional finite element analysis, observed that posterior implants inclined distally could reduce stress transmitted to the bone (Zampelis et al. 2008). Likewise, Bevilacqua et al. (2008), in a three-dimensional finite element study, suggested that the inclination of the distal implants optimizes the distribution of anteroposterior support, reducing biomechanical stress (Bevilacqua et al. 2008).

Occlusal Pattern

There is a great controversy in the literature regarding the occlusal patterns that should be established in implant rehabilitation. The relationships among the occlusal pattern, masticatory muscles, masticatory efficiency, bruxism, and

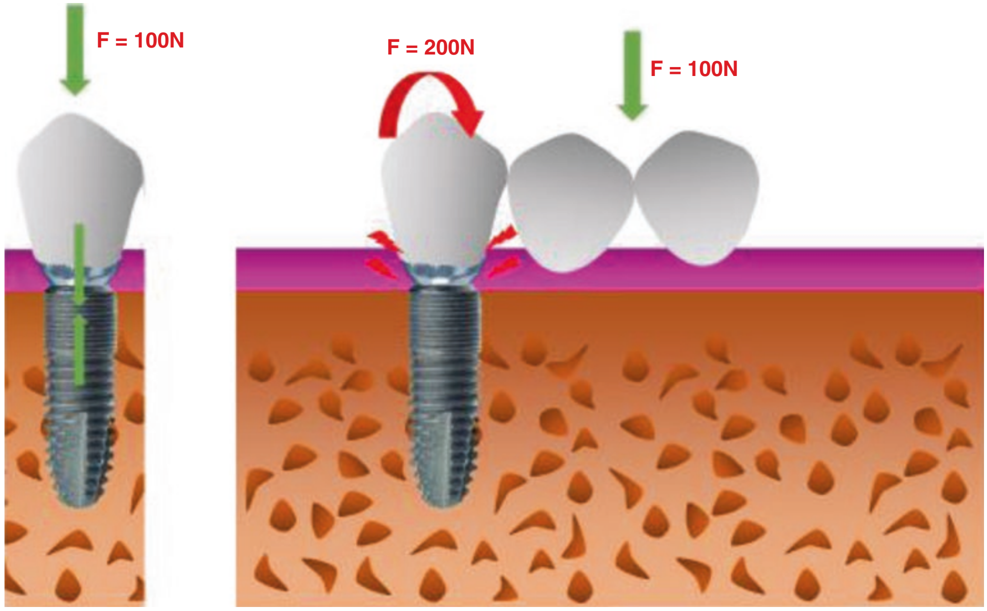

Fig. 9 Effect of overhang on the implant-prosthesis connection

temporomandibular joint structures influence the distribution and intensity of forces (Abou-Obaid et al. 2016).

Occlusion in Immediate Loading

In general, we can establish a series of generic rules referred to occlusion in immediate loading: the occlusal surface should be smaller than in the case of the natural tooth; the contacts should be centered; the cusps should not have great angulations; abrupt anatomical features are to be avoided; symmetrical distribution of the chewing forces should be ensured; cantilevers are to be avoided; and a soft diet should be prescribed. Within edentulism, we can distinguish between unitary or partial absences and fully edentulous arches:

Unitary and Partial Absences

In excursion movements, any kind of occlusion of the restorations is to be avoided, in the same way as non-axial forces, in order to minimize bone loss during the osseointegration period of the implants. There is greater controversy in relation to centric movements. Some authors such as Calandriello et al. (2003) affirm that in good quality bone, slight centric contacts can be given to the posterior teeth. Other authors choose to leave the immediate restorations without occlusal contacts during the first 3 months of osseointegration of the implants, in order to reduce any risks related to forces of this kind—defining the term “nonfunctional immediate teeth,” which resulted in success rates similar to those of unit teeth loaded in a conventional manner.

Fully Edentulous Arches

In immediate implant-supported fixed rehabilitation, controlled mutually protected occlusion is recommended, with group function and slight anterior function. In immediate mucosal overdentures, the occlusion to be chosen comprises bilateral balance. In general, for a full arch, we would need a minimum of four implants. According to authors such as Wennerberg et al. (2001), using an adequate number and distribution of implants may be more decisive than the occlusal scheme involved (Wennerberg et al. 2001). A scheme for occlusal adjustment approach according tooth absence type is depicted in Table 1.

Agents External to Immediate Loading

We considered it important to review the literature on immediate loading in relation to the diet to be followed and parafunctional habits such as bruxism. Another conditioning factor is the type of antagonist arch (Fig. 10a–l).

Antagonist Arch

The type of antagonist directly affects the magnitude of the incident forces. The natural dentition provides greater protective proprioception against excessive forces than implant-supported rehabilitation. A removable prosthesis, whether with or without implants, exerts smaller forces than a fixed antagonist. Likewise, acrylic absorbs more loads than porcelain, which transmits them to a greater extent to the implant-prosthesis system. This consequently is a conditioning factor to be taken into account in planning rehabilitation, together with other factors such as patient age and sex or bone density.

Table 1 Occlusal adjustment considerations for immediate loading restorations

Edentulism		Type of restoration	Considerations in immediate loading
Single tooth	Anterior	Single crown	• No static or dynamic contact with antagonists teeth
	Posterior	Single crown	• No static or dynamic contact with antagonists teeth
			• Reduction of bucccolingual width of occlusal table and buccolingual dimension crown
Multiple teeth	Anterior	Splinted units or single crowns	• Splint the elements
			• No static contact with the antagonist teeth
			• Where possible, maintain excursive guidance on natural teeth
			• Otherwise, minimize vertical superimposition (overbite) and create guidance pathways that are as flat as possible, ensuring disocclusion of posterior teeth
	Posterior	Splinted units or single crowns	• Splint the elements
			• No static contact with the antagonist teeth
			• Where possible, maintain excursive guidance on natural teeth
			• Otherwise, slight contact and marked reduction of buccolingual width of occlusal table and of buccolingual dimension crowns
			• If maxillary implant are positioned palatally, create crossbite Iingualized occlusion to reduce cantilever arm and improve axial loading
Complete edentulism	Maxilla or mandible	One piece fixed prostheses with posterior cantilevers or removable prosthesis (overdenture) on milled bar supported exclusively by implants	• Avoid or minimize length of cantilevers
			• Simultaneous bilateral point contacts on all teeth, excluding teeth distal to implant emergence
			• In lateral movements, group function or guidance with a flat linear pathways and minimal vertical superimposition, excluding teeth in the cantilever
			• In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathways and minimum vertical superimposition
			• Even if the implant-supported prosthesis is opposed by a removable full denture, in excursive movements, avoid balancing contacts at the cost of making the prosthesis unstable
	Maxilla or mandible	Fixed prosthesis without posterior cantilever (in one or more pieces)	• Simultaneous bilateral point contacts on canines and posterior teeth and absence of static contact incisors
			• In lateral movements, group function or guidance with flat linear pathways and minimum vertical superimposition
			• In protrusive movements, guidance full dentures, distributed on all anterior teeth, including canines with flat linear pathways and minimum vertical superimposition
			• Even if the implant-supported prosthesis is opposed by a removable full denture, in excursive movements avoid balancing contacts at the cost of making the prosthesis unstable
	Maxilla or mandible	Removable prosthesis (overdenture) on single retention devices or on cast liar supported by implants and mucosa	• If possible, do not use a removable prosthesis for immediate loading. If there is no alternative, follow these guidelines
			• Opposed to natural dentition of a fixed prosthesis
			• Simultaneous bilateral point contacts on canines and posterior teeth and presence of static contact on incisors
			• In lateral movements, groups function or guidance with flat linear pathways and minimum vertical superimposition
			• In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathway and minimum vertical superimposition
			• Opposed to full denture; In excursive movements, seek one or more balancing occlusal contacts

Fig. 10 (**a**) Occlusal plane collapse in bruxist patient. Preoperative clinical situation. (**b**) Preoperative clinical situation. Lateral view. (**c**) Metal-ceramic bimaxillary full-arch implant-supported fixed prostheses. Clinical image of prosthetic abutments and keratinized tissue in the upper jaw. (**d**) Prosthetic abutments and keratinized tissue in the lower jaw. (**e**) Placement of bimaxillary metal-ceramic implant-supported rehabilitation. (**f**) Multiple chipping of veneer ceramic and wear of the metal supra-structure after 6 months of prosthetic load. (**g**) Upper jaw occlusal view of ceramic chipping and metal wearness. (**h**) Lower jaw occlusal view of ceramic chipping and metal wearness. (**i**) Afterward 2 years of full-arch metal-ceramic rehabilitation, it is decided to change the prostheses material to metal-resin material rehabilitations. (**j**) Image of wear and fracture of the resin coating material with metal exposure of the mesostructure after one and a half years of funcional loading. (**k**) In the same case, due to the inadequate behavior of prosthodontic materials by its parafunction, a new bimaxillary rehabilitation is proposed with titanium meso-structure manufactured with CAD-CAM and ceromer coating (a hybrid material with ceramic and composite), easily to repair in office. Upper occlusal view picture. (**l**) Metal-ceromer implant-supported prosthesis. Lower jaw occlusal view

Fig. 10 (continued)

Diet Consistency

With regard to diet, Calandriello et al. (2003) argued that no type of diet restriction is necessary when carrying out immediate loading (Calandriello et al. 2003). On the other hand, Misch (1999) chose to follow a soft diet during the healing period of the implant. Another study recommended a liquid diet during the 2 weeks after immediate loading, followed by a soft diet for 5 months (Misch 1999).

Masticatory Parafunctional Habits

One of the main contraindications of immediate loading is bruxism. Parafunctional habits go against our interests from the point of view of osseointegration. The intensity of the forces in such situations is 20 times greater than normal; they act for hours instead of minutes; and their more horizontal direction and shearing effect ultimately creates an unfavorable setting for optimal osseointegration (Misch et al. 2004) (Fig. 11).

Fig. 11 Adhesive fracture with metal exposition of implant-supported crown due to occlusal overloading by bruxism

In patients of this kind, when restoration with immediate loading is required, it is advisable to achieve a good occlusal balance, together with rigid fixation by means of the provisional prosthesis, which in turn must have good passive fit. However, many authors agree that bruxism is a contraindication when it comes to planning immediate loading, due to the high number of failures (Gapski et al. 2003). In this regard, losses most often affect implants in the upper maxilla (Grunder 2001).

On the other hand, it should not be forgotten that bruxism and parafunctional occlusal forces are factors that increase prosthodontic complications in treatments with immediate loading, causing loosening of the screws and fractures of provisional prostheses, which usually increases the risk of implant loss (Misch 2005).

Nonetheless, scare scientific conclusive evidence about bruxism in implantology exists. Because the relative risk of implant failure and technical/biological complications associated significantly to this factor creates a low associated and precision of data (Chrcanovic et al. 2015; Zhou et al. 2016) (Figs. 12a–j).

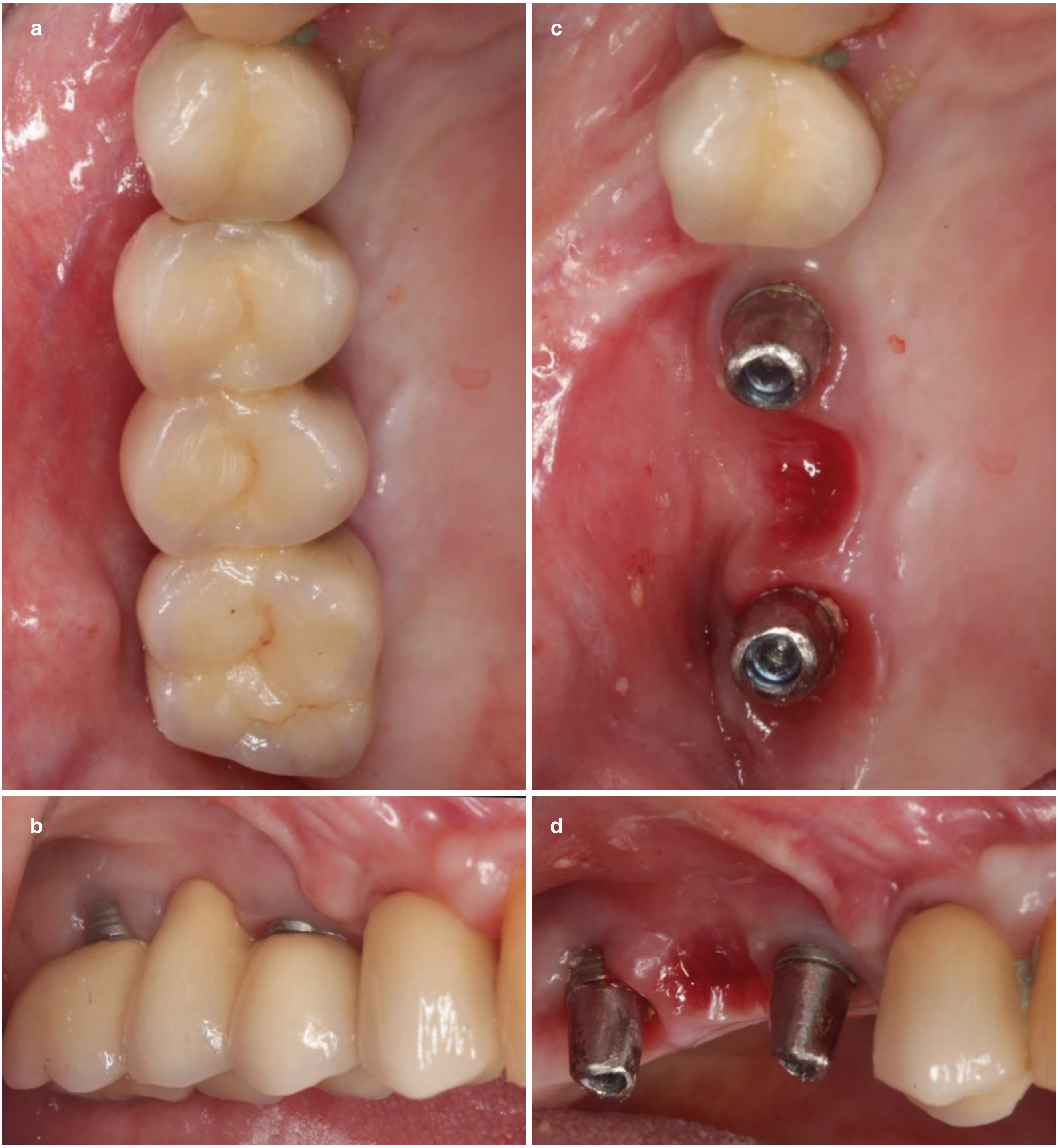

Fig. 12 (**a**) Occlusal view of implant-supported cemented bridge in the posterior zone in a bruxist patient. The patient refers pain at percussion and masticatory function. (**b**) In the lateral view of fixed prosthesis, a peri-implant soft tissue recession in both implants is appreciated. (**c**) Occlusal view of prosthetic abutments. (**d**) Lateral view of prosthetic abutments. (**e**) Occlusal view of implant connections after prosthetic abutment removal. (**f**) Dental implants explantation. Occlusal view of implant site. (**g**) Extraoral picture of extracted implants. (**h**) Implantation of two dental implants in subcrestal position (VEGA® Klockner®, Barcelona, Spain) after healing period. (**i**) Occlusal view of screw-retained partial-fixed prosthesis after 3 months with conventional loading protocol, the parafunction was addressed by means of discharge occlusal splints. The occlusion is exhaustive assessed to avoid an occlusal overload (secondary occlusion). (**j**) After 3 months of prosthetic load, the keratinized mucosa in the buccal side of both implants can be appreciated. Lateral view

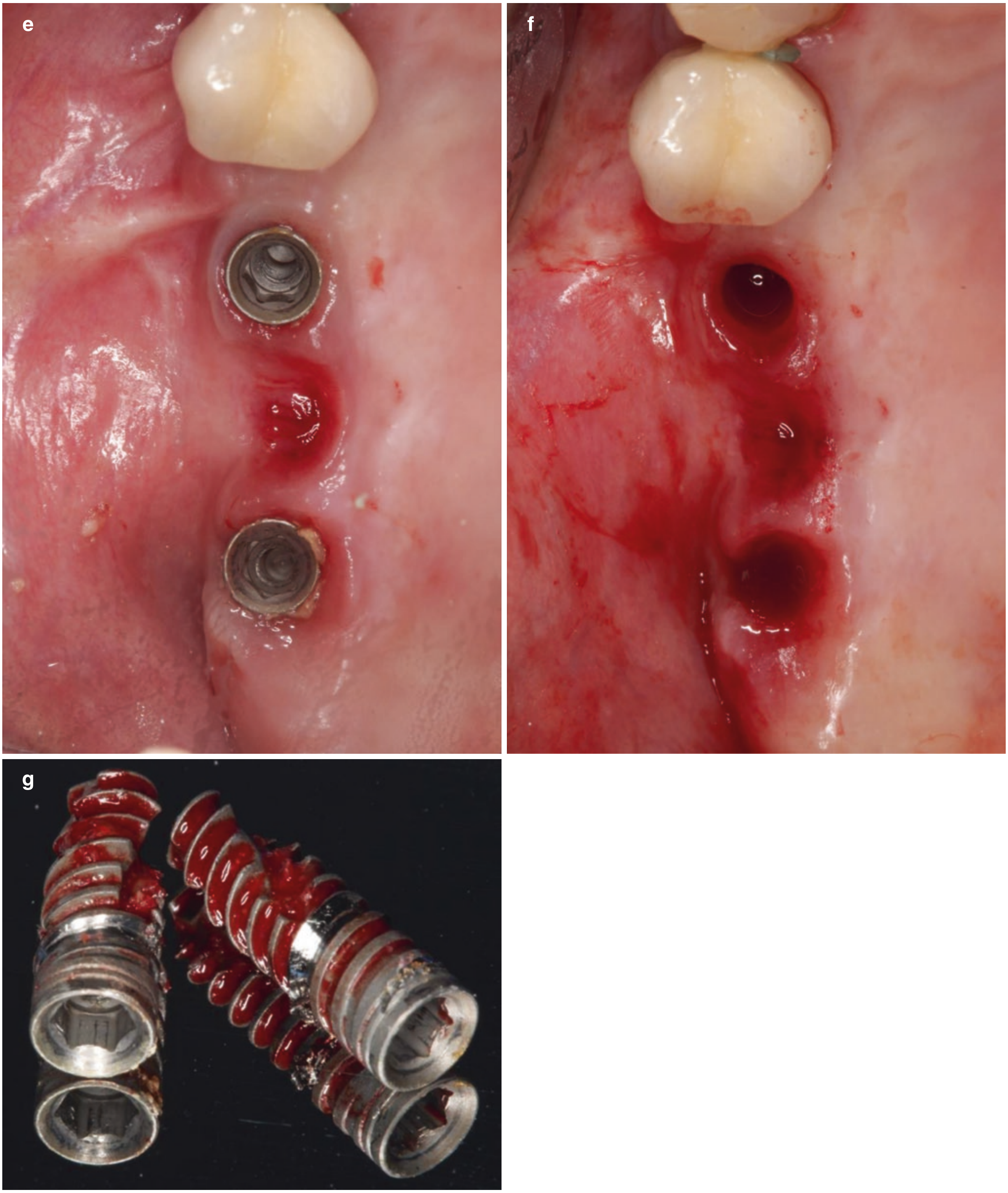

Fig. 12 (continued)

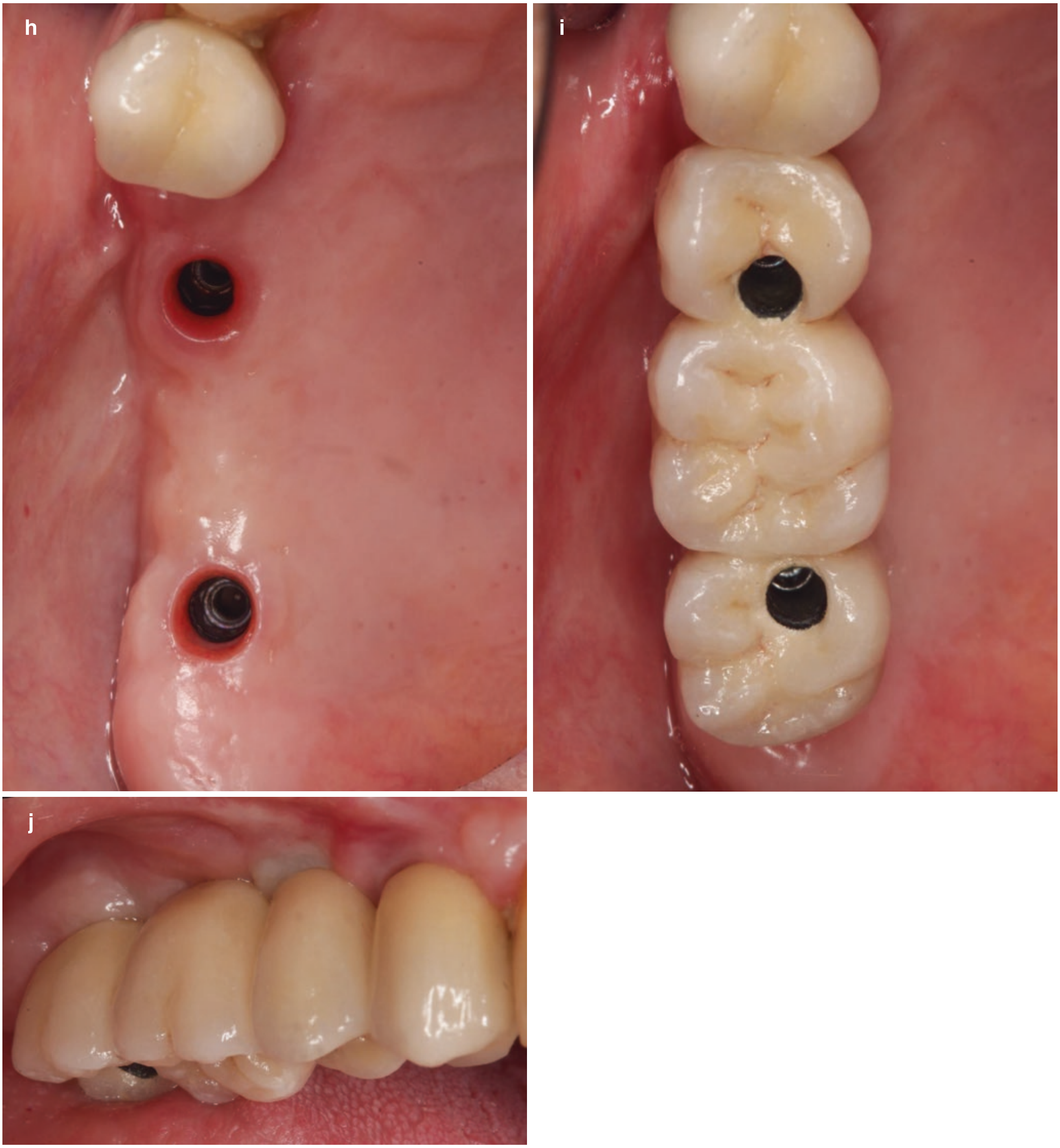

Fig. 12 (continued)

Occlusal Adjustment Procedures

The prerequisite for the prevention of the consequences of occlusal overload is the detection, measurement, and quantification of the latter both in natural teeth and in implant-supported structures.

Conventional methods for controlling and adjusting occlusion include articular papers, fabrics and vinyl, as well as shim stock strips. The thickness of these materials for clinical use varies between 8 and 40 μm, with the use of thicknesses of up to 200 μm in laboratory work.

The problem with these procedures is that the information obtained regarding the occlusal load is conditioned to operator experience and to the subjective perception of the patient, which is imprecise since the sensory receptors are subjected to adaptation. These methods allow the localization of the constacts and provide information on the number and distribution. However, these are unable to evalute the sequence in which they appear during the occlusion procedure or their intensity (Kerstein and Radke 2014).

Accurate Occlusal Adjustment: T-Scan®

This lack of precision in reliably associating the size, intensity, and appearance of the marks and the forces they represent has led to the development of objective procedures based on the measurement of occlusal forces through digitized systems, such as the T-Scan® (Fig. 13), which is capable of locating the contacts and quantifying the incident forces, expressed in absolute or relative units (Fig. 14.).

In one of the few studies performed with the T-Scan® in patients with osseointegrated implants, Dario (1995) analyzed occlusion in 100 implant-bearing patients using the

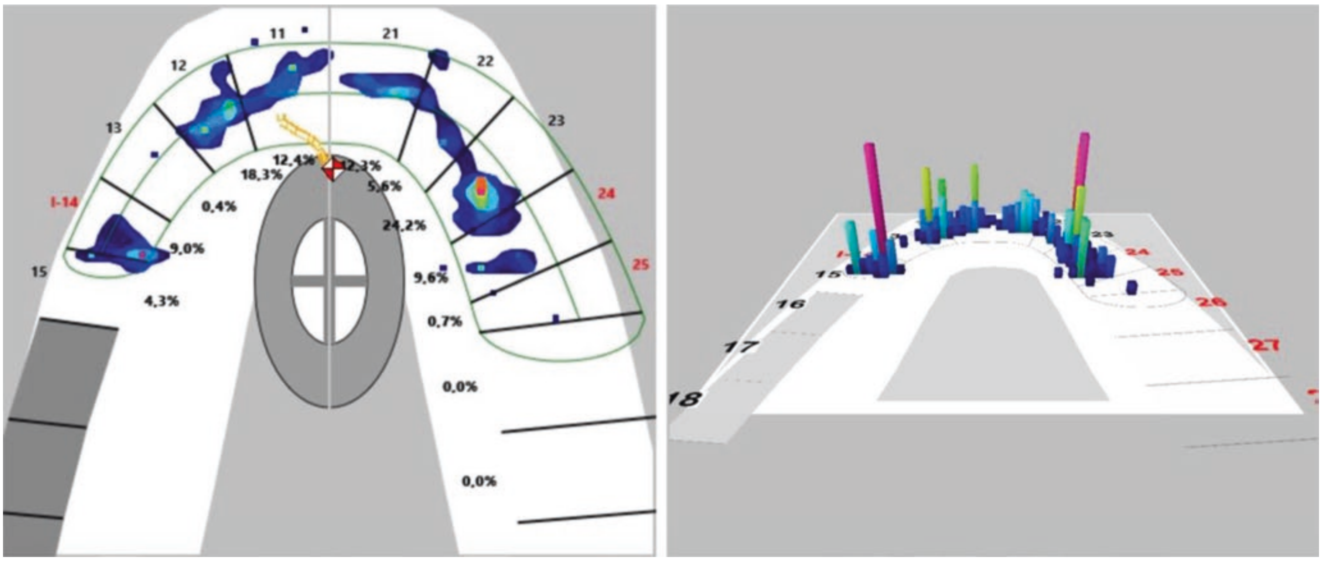

Fig. 13 Sample T-scan III® image of occlusal contacts after occlusal adjustment

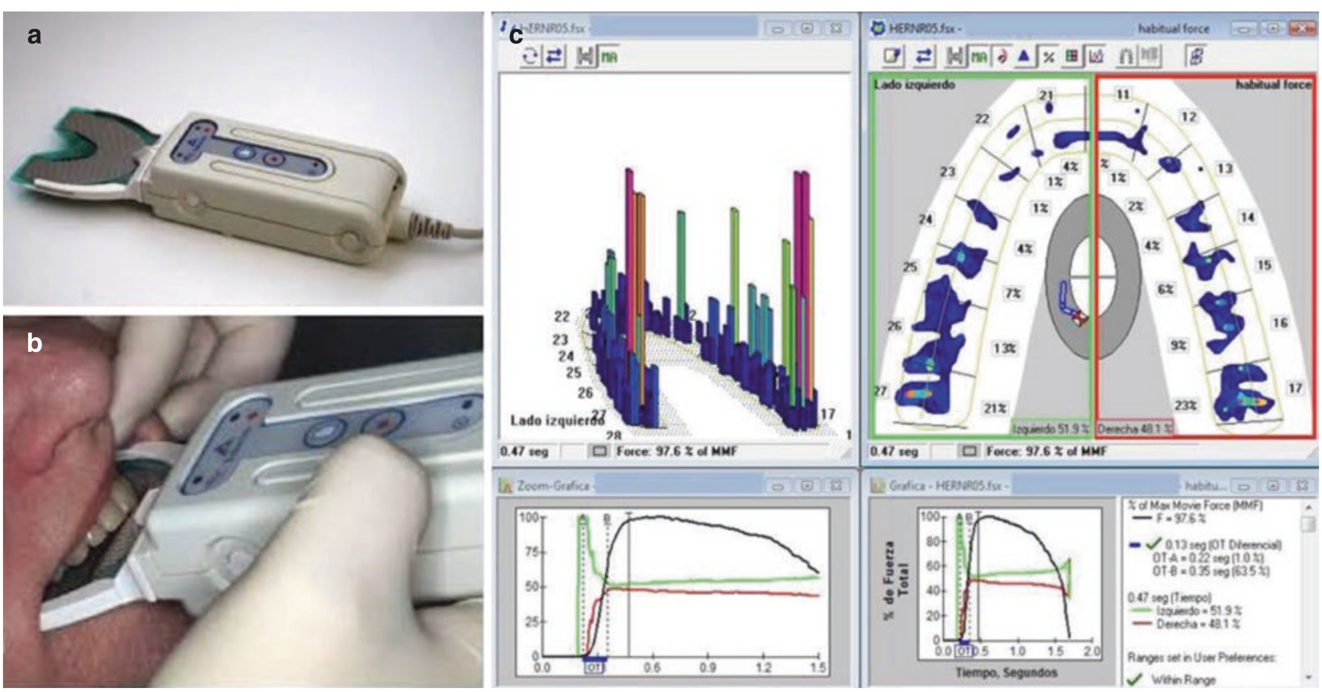

Fig. 14 T-scan® handpiece. (**a**) Wired T-scan® handpiece model with sensor inserted (green color margins and metal gray occlusion plate). (**b**) T-scan® handpiece clinical occlusion test. (**c**) T-scan™ software monitor display indicates the intensity of occlusal contacts; it is represented with intuitive color bars indicating intensity of occlusal contact. Also, it provides graphs with quantitative data and percentages for both left and right arch sides

T-Scan® and found that the occlusion of a prosthesis over implants can change significantly in the first 18 months after placement, since almost half of the patients needed occlusal adjustment during the observation period (Dario 1995).

On the other hand, occlusal analysis systems such as the T-Scan® are able to detect the sequence of occlusal contacts, offering the operator the possibility of eliminating those contacts that prevent achieving the objective of a non-simultaneity pattern. In the case of rehabilitation with implant-supported prostheses in partially edentulous patients, the different cushioning of these structures compared to natural teeth imply that occlusal contact should occur once the teeth have been depressed inside of the alveolus. If the contact pattern in these cases is simultaneous, the artificial structures will become overloaded.

However, in implant-supported restorations in totally edentulous patients, we should seek a pattern of simultaneity of the occlusal contacts, which allows us to achieve bilateral, simultaneous, and symmetrical occlusal contacts and a distribution of the occlusal load in a balanced way on both sides of the middle sagittal plane. Having this objective information eliminates possible biases derived from subjective operator interpretation of the visual or tactile data obtained from articular or shim stock paper, as well as the proprioceptive sensation of the patient—the latter being influenced by factors such as subjectivity in itself, proprioceptor accommodation, or accumulated fatigue during the clinical session.

A previous study investigates the relation between occlusal load and peri-implant clinical parameters and crevicular fluid volume in patients wearing full-arch implant-supported fixed prosthesis (Pellicer-Chover et al. 2014). Authors failed to detect differences on clinical parameters but observe a higher crevicular fluid secretion on patients with high occlusal load pattern. This parameter was normalized after detection and adjustment of occlusal contacts using the T-Scan® III device. The results were assessed at 8, 16, and 52 weeks (Fig. 15).

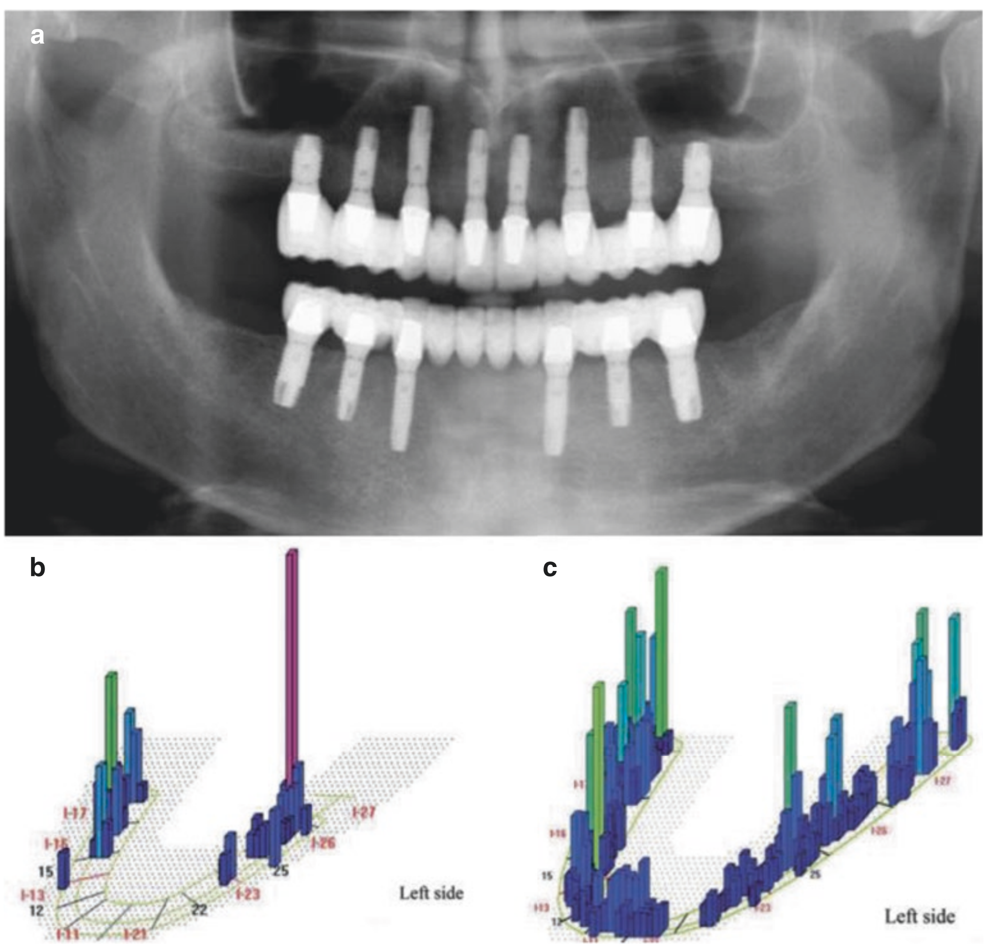

Fig. 15 Occlusal adjustment of bimaxillary implant-supported full-arch fixed restoration. (**a**) Patient orthopantomograph (Phibo TSA®, Phibo Dental Solutions, Sentmenant, Barcelona Spain). (**b**) Sample T-scan III® image of occlusal contacts before occlusal adjustment (week 4). (**c**) Sample T-scan III® image of occlusal contacts after occlusal adjustment (week 16)

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Part II

Clinical Considerations for Diagnosis During Treatment Planning

General Diagnosis and Medical Evaluation

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Abbreviations

CAD/CAM	Computer-aided design/Computer-aided manufacturing
Ncm	Torque insertion Newton's per centimeter

Take-Home Message
Appropriate patient selection and careful surgical and prosthetic planning are essential to achieve predictable outcomes of immediately loaded implants. Advance in implant surface design, diagnostic tools, and biological knowledge of bone healing process allows immediate loading also in more demanding clinical situations (systemically compromised patients, low quality bone, complex rehabilitations).

General Diagnosis

Current literature does not contribute to a high level of evidence regarding possible indications for immediate loading. A great variety of exclusion criteria for immediate loading of dental implants are used in different studies. However, the reported criteria are similar to those chosen for conventional loading of dental implants. Despite its several clinical advantages, the immediate loading protocol should be performed respecting a rigorous preliminary diagnostic algorithm (Bahat and Sullivan 2010). In fact, immediate loading might come with unexpected/not-budgeted adjunctive surgical or prosthetic procedures. Therefore, discussion with the future patient of possible complications is mandatory.

Before surgical intervention, the patient must go through an accurate medical anamnesis and physical examination. The physical examination prior to implant treatment is both extraoral and intraoral. The extraoral evaluation includes the exam of the perioral soft tissues, the lips, the nasolabial groove, the mouth corners, the facial symmetry, and the smile line. The analysis of those items helps the clinician in designing a mimetic prosthetic rehabilitation and in considering the eventual need of additional treatments such as presurgical orthodontics (Figs. 1a–f and 2a–q).

A complete photographic record of the visit is complementary to the physical examination. Digital photography has led to significant improvements in patient-dentist communication and in communication between the dentist and the dental technician. Furthermore, digital photography, along with advanced visualization software, allows a more throughout and repeatable analysis of the esthetic measurable parameters over time. The minimal set of photographs for each implant patient should include occlusal views (upper and lower), lateral views, frontal views, and also a full-face frame.

The intraoral exam includes the inspection of oral mucosa and periodontal tissues, the palpation of target sites, the evaluation of the residual teeth, the vestibular fornix, and the shape of the edentulous alveolar ridge. The

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Fig. 1 (**a**) Extraoral panoramic radiograph, congenital absence of second lower premolars, and persistence of deciduous molars. (**b**) Intraoral view with orthodontic appliances. (**c**) Extraoral panoramic radiograph after deciduous teeth extraction. (**d**) Occlusal view of the lower arch with implants placed (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**e**) Occlusal intraoral view after 6 months of prosthesis delivery. (**f**) Panoramic extraoral radiograph at 6 months of loading

shape of adjacent teeth and the interproximal contact point are factors to take into account when esthetic results are pursuit. In teeth with square shapes, it is easier to reach a good esthetic result, while in more triangular teeth, papilla formation is essential to avoid interproximal black triangles (Fig. 3a, b).

Of particular importance is the implant prosthetic evaluation including interproximal spaces (Figs. 4a–d and 5),

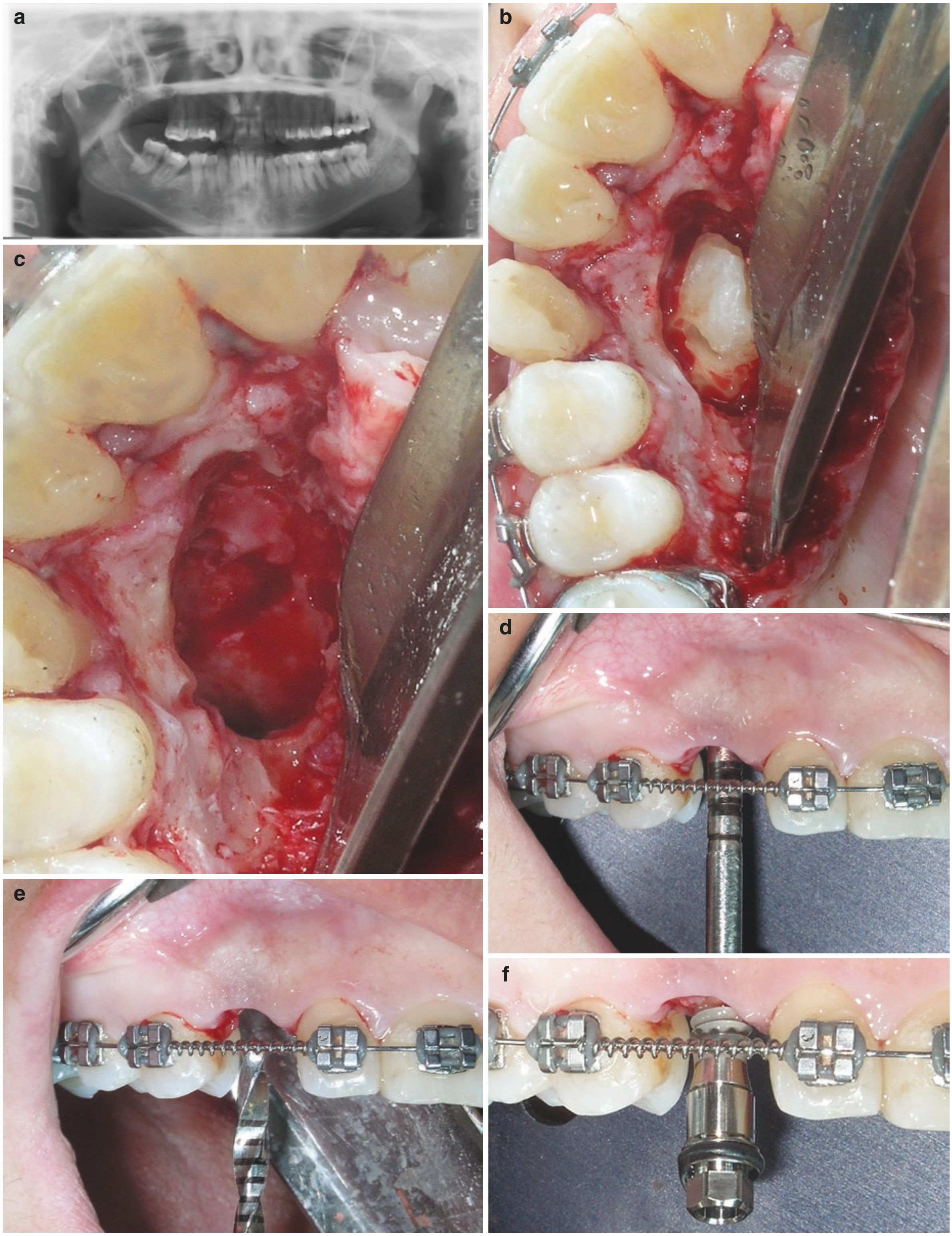
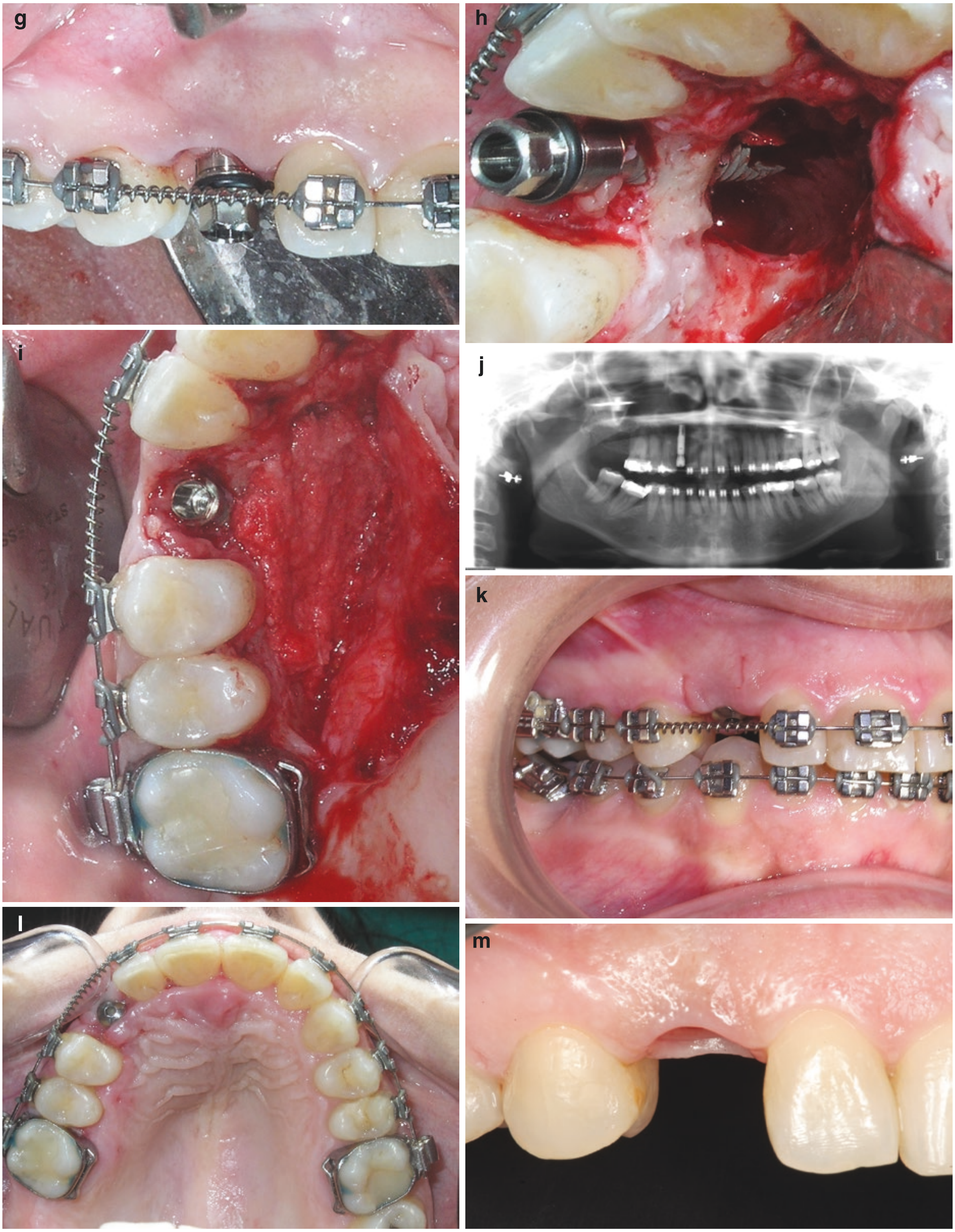


Fig. 2 (**a**) Impacted upper right canine with no possibility of orthodontic extrusion due to its higher position close to the apex of adjacent teeth. (**b**) Patient underwent orthodontic treatment to create enough mesiodistal space to put an implant in the canine position. A full-thickness palatine flap was raised. After ostectomy, the included tooth was exposed. (**c**) After tooth section, the crown and root were extracted separately. (**d**, **e**) Implant bed preparation with a sequence of osteotomes and drills. (**f**) Intraoperative image of Phibo 4.2 × 16 mm implant placement (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**g**) Implant installation. (**h**) Palatal view. The implant was anchorage in the alveolar crest and the bottom of bone cavity (nasal cavity floor). (**i**) The bone cavity was filled with autogenous bone particles. (**j**) Extraoral panoramic radiographic after implant placement. (**k**) Clinical view at suture removal 1 week after implant placement. (**l**) Occlusal view at 1 week control. (**m**) After 3 months, orthodontic treatment was removed and definitive impressions were taken. (**n**) Definitive prosthetic abutment in place. (**o**) Definitive prosthesis delivery. (**p**) Occlusal view of the definitive restoration in place. (**q**) Extraoral panoramic radiograph after 1 year of prosthesis delivery



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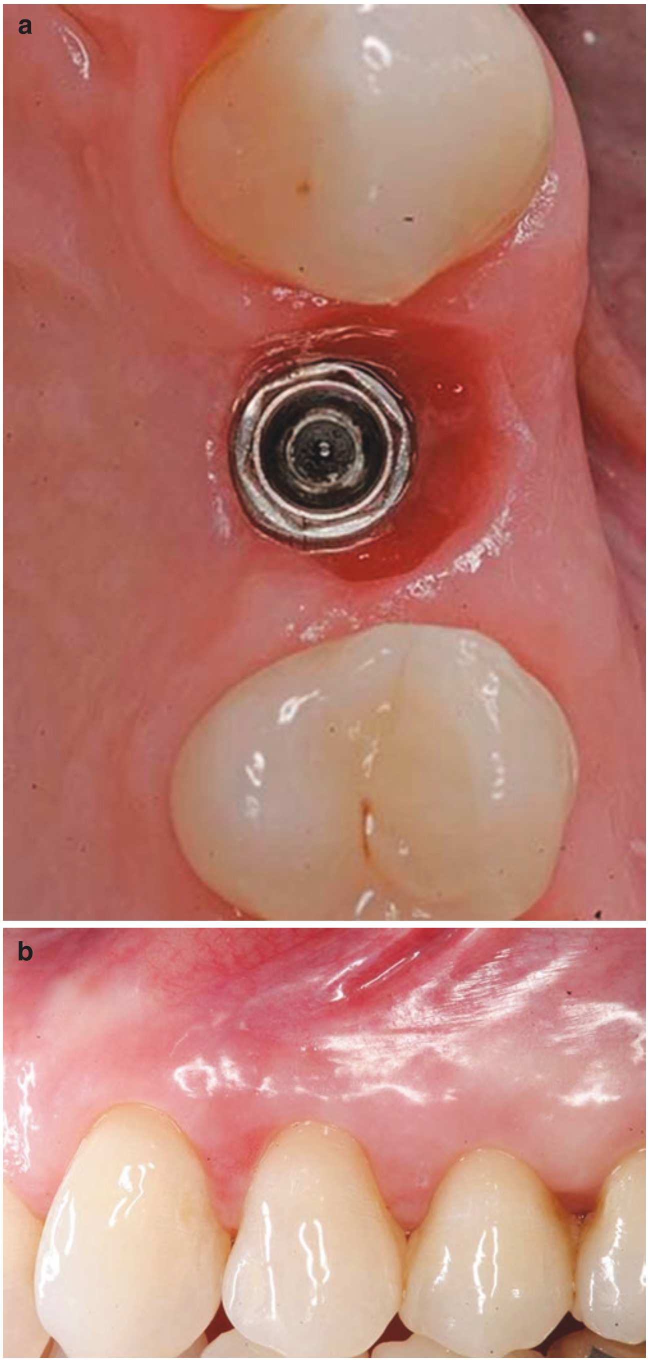


Fig. 3 (**a**) Patient presenting triangular teeth shape and thin gingival biotype. The implant was placed palatally to increase the amount of keratinized tissue on the buccal side. Compare the soft tissue thickness regarding the adjacent teeth. (**b**) Clinical view at 12 months after prosthesis delivery

vertical dimension, compatible occlusion, and relationship with the antagonist dentition (Fig. 6a, b). In fact, an unbalanced occlusal scheme with the opposite arch might promote implants and prosthesis failure when an immediate loading protocol is pursued. With the aid of dental casts and diagnostic wax-up, the clinician must consider all of the available treatment options discussing them with the patient. For a detailed prosthetic diagnosis, please refer to Chap. 7.

Advanced imaging and CAD–CAM technologies are helpful in the evaluation of available bone quality within computer-aided surgical planning and immediate restoration confection before implant placement and its immediate loading in the same operative day (Fig. 7(1–36). In fact, most of the authors find that good bone quality is an important prognostic factor for the final success (Nkenke and Fenner 2006). Favorable bone repair and formation and also the distribution of mastication forces are guaranteed by adequate primary implant stability. Primary stability is mechanically mediated by macro-retentions of the implant surface to the bony walls of the implant bed. Therefore, modifications of implant micro- and macrostructure have been introduced to increase implant primary stability and new bone formation under immediate or early loading protocols (Coelho et al. 2009). Empirically, authors chose the insertion torque as a measure of primary stability, which is defined as the rotational resistance at the time of implant placement (Friberg et al. 1999; Ottoni et al. 2005). Torque values of 35–40 Ncm and higher have been chosen as putative thresholds for immediate loading (Cannizzaro et al. 2017). However, there is no evidence-based threshold for insertion torque associated to immediate loading. Splinting of the implants for multiunit rehabilitations and reduced occlusal contacts for single implants have been recommended as adjunctive safety measures to prevent implant failure in immediate loading protocols (Esposito et al. 2009).

Patient Selection

Indications to Immediate Loading

Here we present the classification of indications and contraindications to immediate loading according to the author's personal experience (Table 1). Primary indication for immediate implant loading is certainly patients' desire to reduce the overall treatment time. Additionally, several psychological factors, related to the preservation of functional and esthetic outcome, represent solid indications to immediate loading. Patients who are accustomed to edentulism and have been wearing a removable denture for a long time might not perceive any significant discomfort in waiting a few more months to get their final restoration. On the contrary, a recent trauma in the esthetic area or the sudden need for extraction

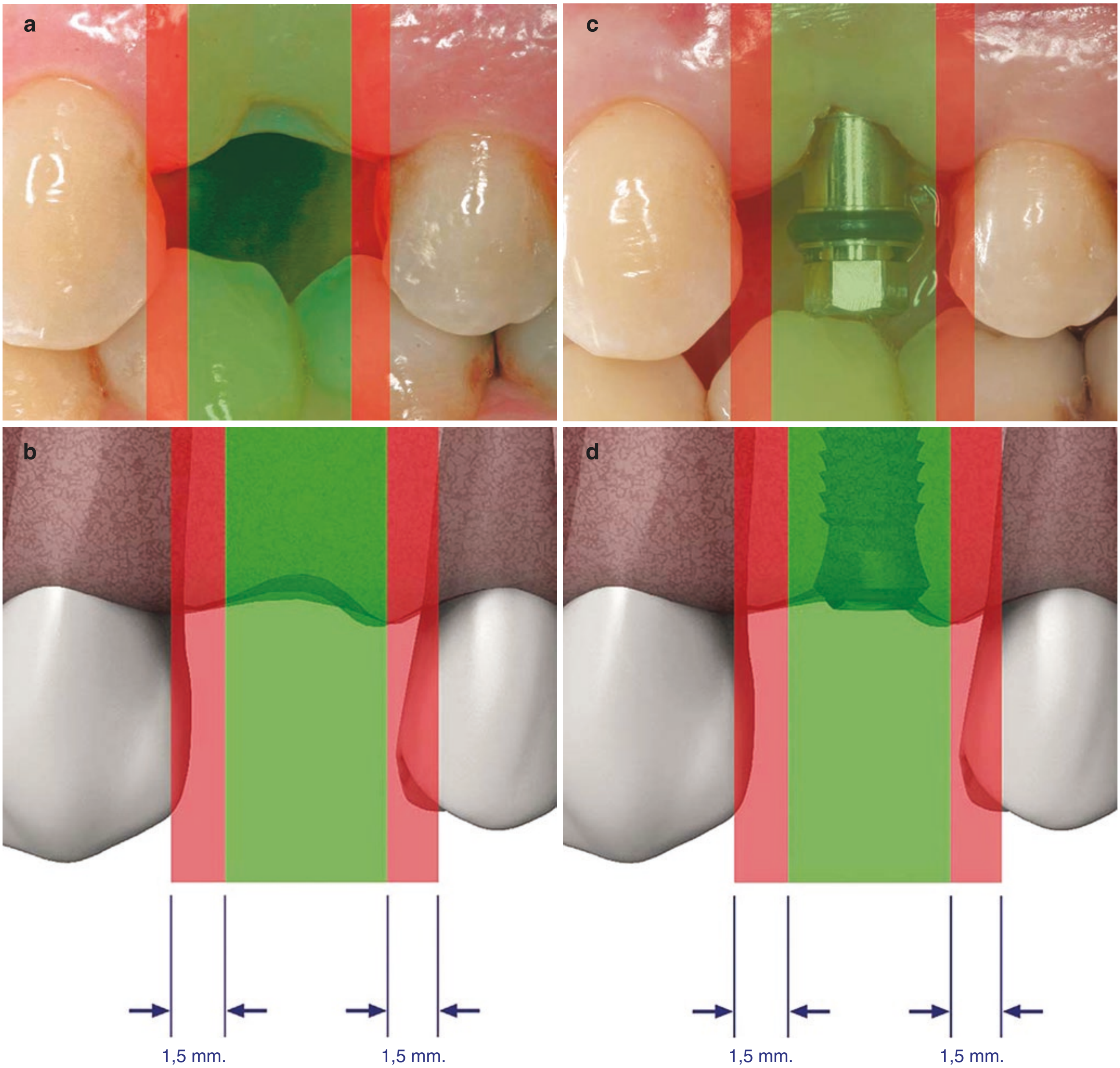


Fig. 4 (**a**) A minimum distance of 1.5 mm between implant and dental roots of adjacent teeth is suggested. The implant placement must be performed within comfort zone (green color). The "risk zone", which is represented in red, is the one in which the implant is located closer and less than 1.5 mm from adjacent teeth. (**b**) The implants must be placed into the green area. (**c**) Flapless implant placed within the comfort zone. (**d**) Scheme of implant placed maintaining an adequate space with the adjacent teeth and outside red zone

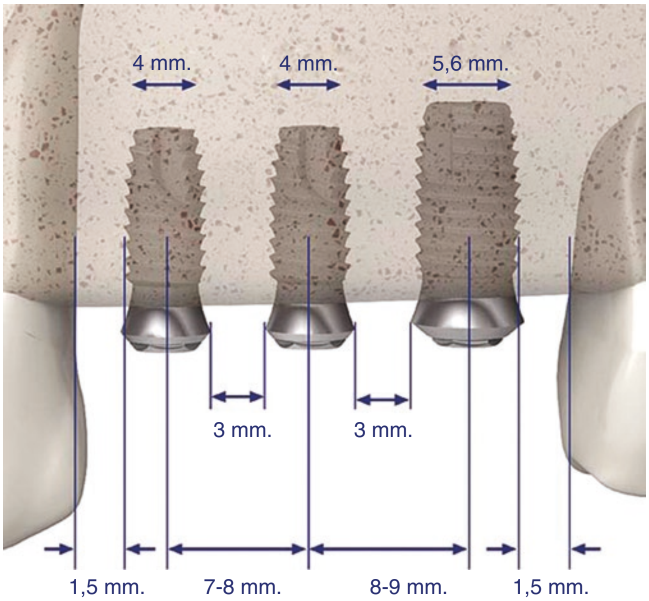


Fig. 5 Schematic representation of the minimum mesiodistal space required to treat a partial edentulous space with different implant metrics

of several compromised teeth present a challenge to patient acceptance of delayed loading implant therapy (Fig. 8a–r).

The patient should be at least 18 years old and able to sign an informed consent form. In order to provide a more favorable oral environment for implant osteointegration, patients should be compliant to a rigorous program of professional oral hygiene sessions and to adequate domiciliary hygiene habits. Local indications to immediate loading are several, since the feasibility of this approach has been proven in different clinical scenarios: traumatic tooth dislocation/fracture in the esthetic area; edentulous mandible; recently edentulous maxilla; partially dentate mandible and maxilla; and single edentulism in mandible and in maxilla (Fig. 9a–o). The implementation of CAD–CAM technologies may allow us to resolve the case within the same operative day, in particular, in an area with high esthetic compromise (Fig. 10a–e).

A local determinant of success is the presence of a healthy, vascular bone. Even in the presence of sufficient bone height

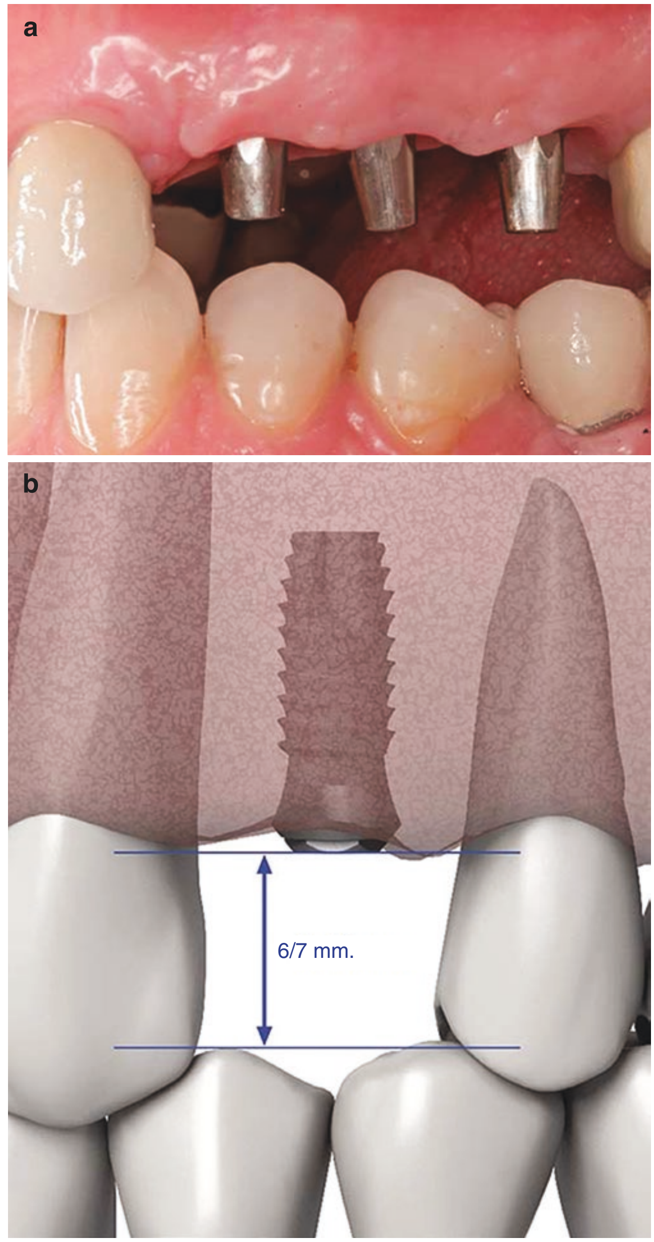
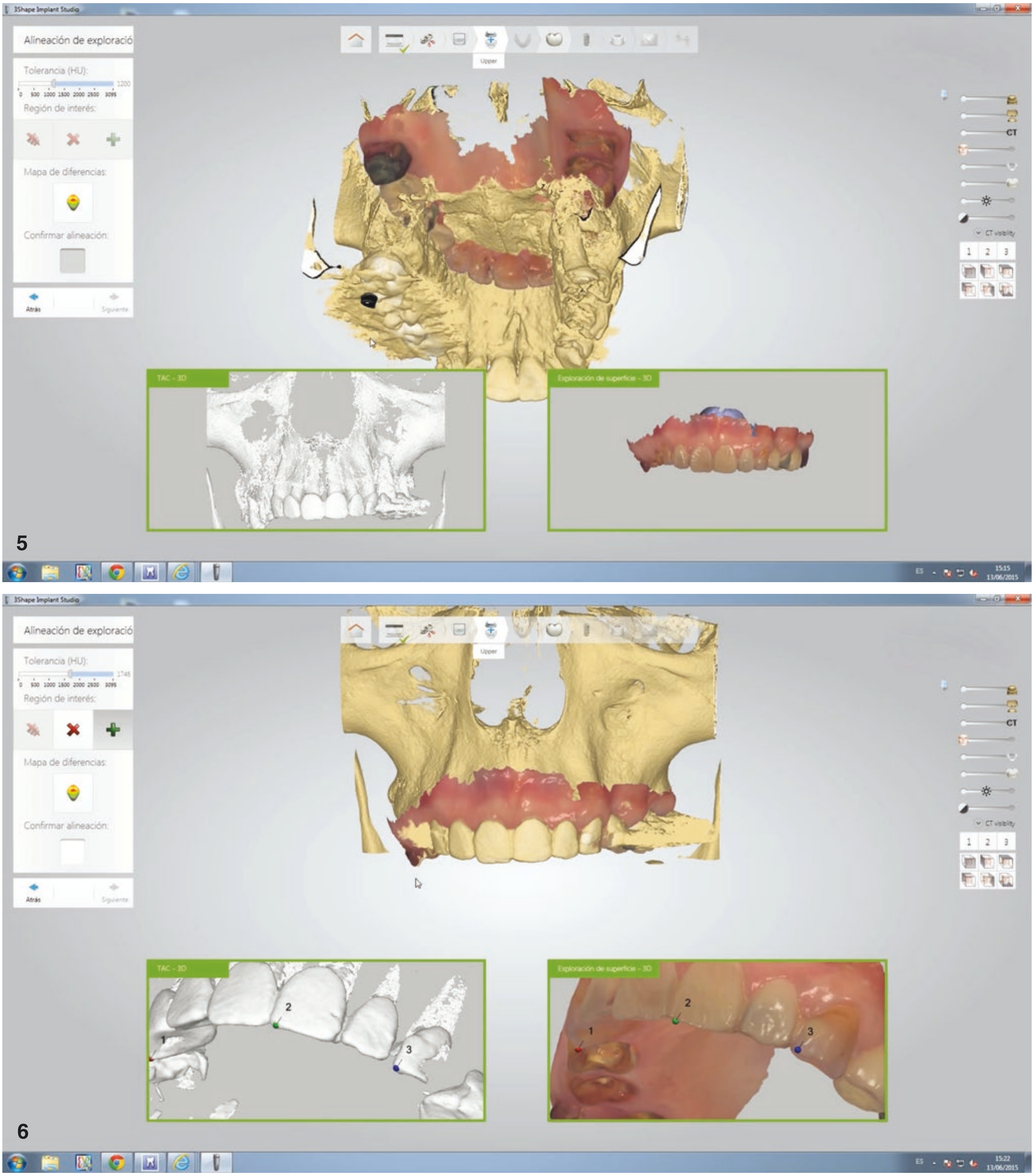


Fig. 6 (**a**) Another factor to take into account is the interocclusal space, which requires at least a minimum of 6–7 mm of height from implant neck to antagonist occlusal plane for prosthetic rehabilitation. (**b**) Schematic representation of prosthetic vertical height

Fig. 7 (1) Intraoral frontal view of patient wearing fixed and removable prosthodontics. (2) Panoramic radiograph of initial situation. (3) Intraoral occlusal view of lower maxilla. (4) Intraoral occlusal view of upper maxilla. (5) CBCT and intraoral scanning superimposition of upper maxilla using a CAD–CAM design software. (6) CBCT and intraoral scanning data were merged in a single-design model. (7) Computer-aided mock-up design for immediate prosthesis confection of upper anterior teeth. (8) Computer-aided mock-up design for immediate prosthesis confection of posterior teeth guided by patient's own fixed prosthesis. (9) CAD modeling of edentulous zone, for final prosthesis design adaptation. (10) CAD final view of both prosthesis designs in posterior zone. (11) CAD frontal view of upper prosthesis designs regarding removable antagonist. (12) Computer-aided implant positioning planning for the upper guided surgery template confection. (13) CAD surgical template with holes for the implants positioning. (14) CBCT and intraoral scanning superimposition of lower maxilla using a CAD–CAM design software. (15) Computer-aided mock-up design for immediate prosthesis confection of lower anterior and posterior teeth. (16) Computer-aided implant positioning planning for the lower guided surgery template confection. (17) The inferior dental nerve is traced in surgical planning to ascertain a proper implant position, to avoid its injury. (18) CAD surgical template with holes for the implants positioning in the lower maxilla. (19) CAD–CAM immediate restoration for the anterior and posterior teeth of the upper maxilla. (20) Surgical splint confectioned through 3D printing. (21) Presurgical 3D-printed model of implant positions planned of the upper maxilla. (22) 3D-printed surgical splint and CAD–CAM immediate restoration for two dental implants in the lower mandible. (23) 3D-printed surgical splint and CAD–CAM immediate restoration for three dental implants of the contralateral side of the lower mandible. (24) Placement of implants through guided surgery splint. (25) Upper implants placed through a minimally invasive technique. (26) The screw-retained immediate restoration was placed and adjusted over the implant connections. (27) Anterior provisional restoration was placed and adjusted. (28) Guided surgery splint in position for implantation. (29) Implant bed drilling through surgical splint in posterior lower mandible. (30) Implant placement after surgical instrumentation of implant beds in posteior lower mandible. (31) Implant placement of the contralateral mandible site. (32) The screw-retained immediate restoration was placed and adjusted over the implants connections. (33) Immediate restoration was placed and adjusted over the implants connections of the contralateral mandible side. (34) Intraoral occlusal view of lower mandible with immediate restorations placed. (35) Frontal view in maximum intercuspation of immediate loading in the same operative day. (36) Postoperative panoramic radiograph



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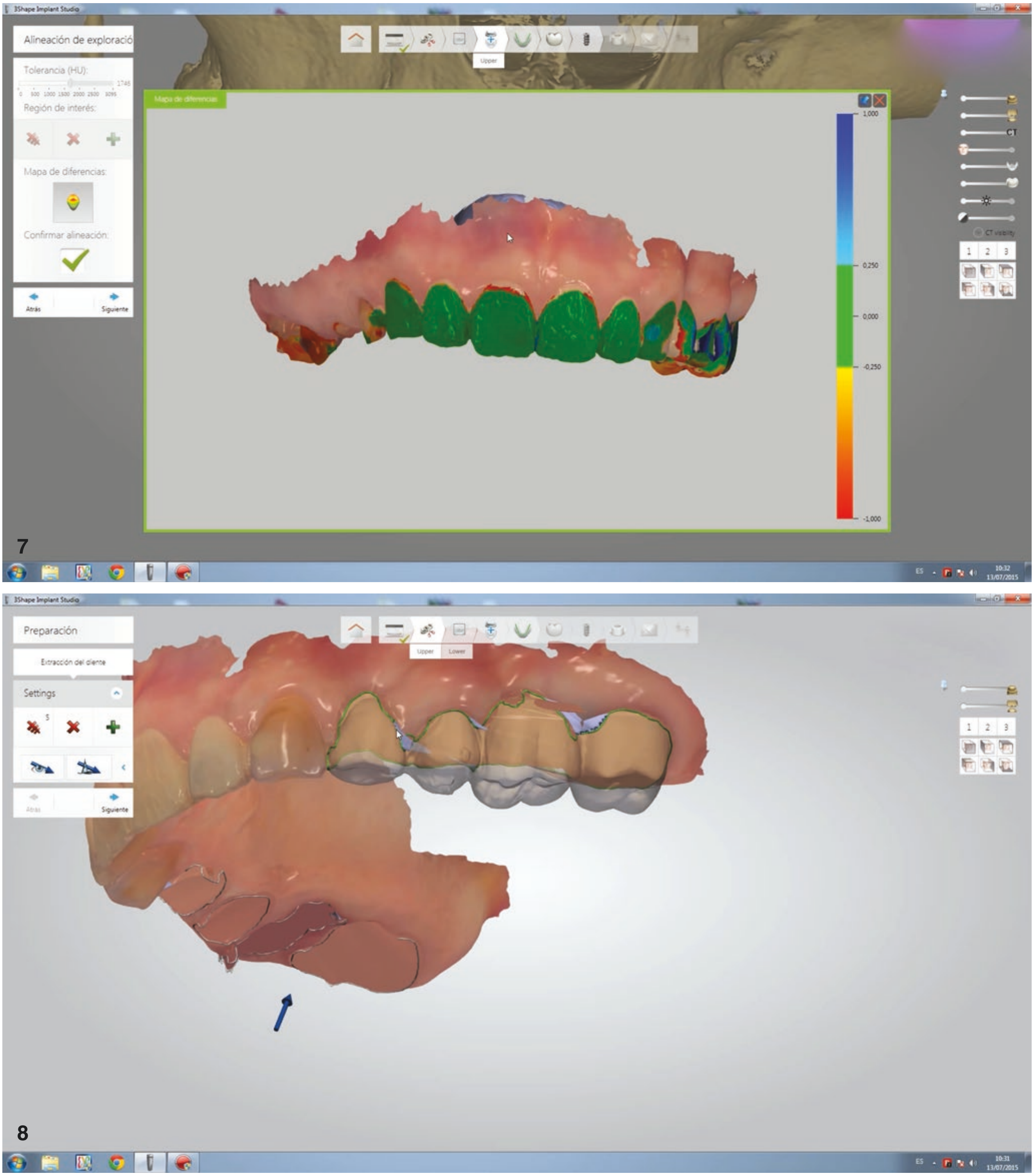

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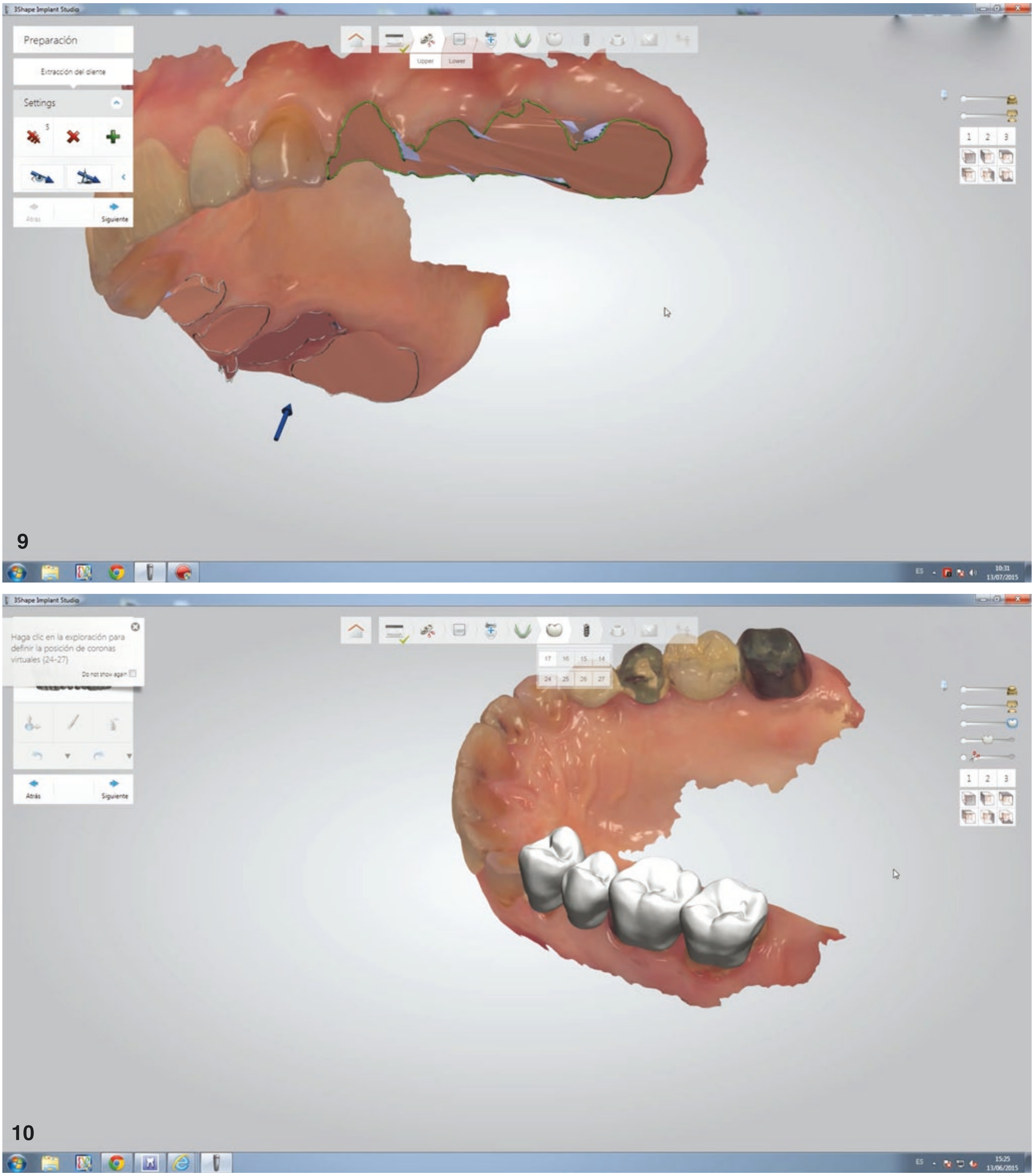

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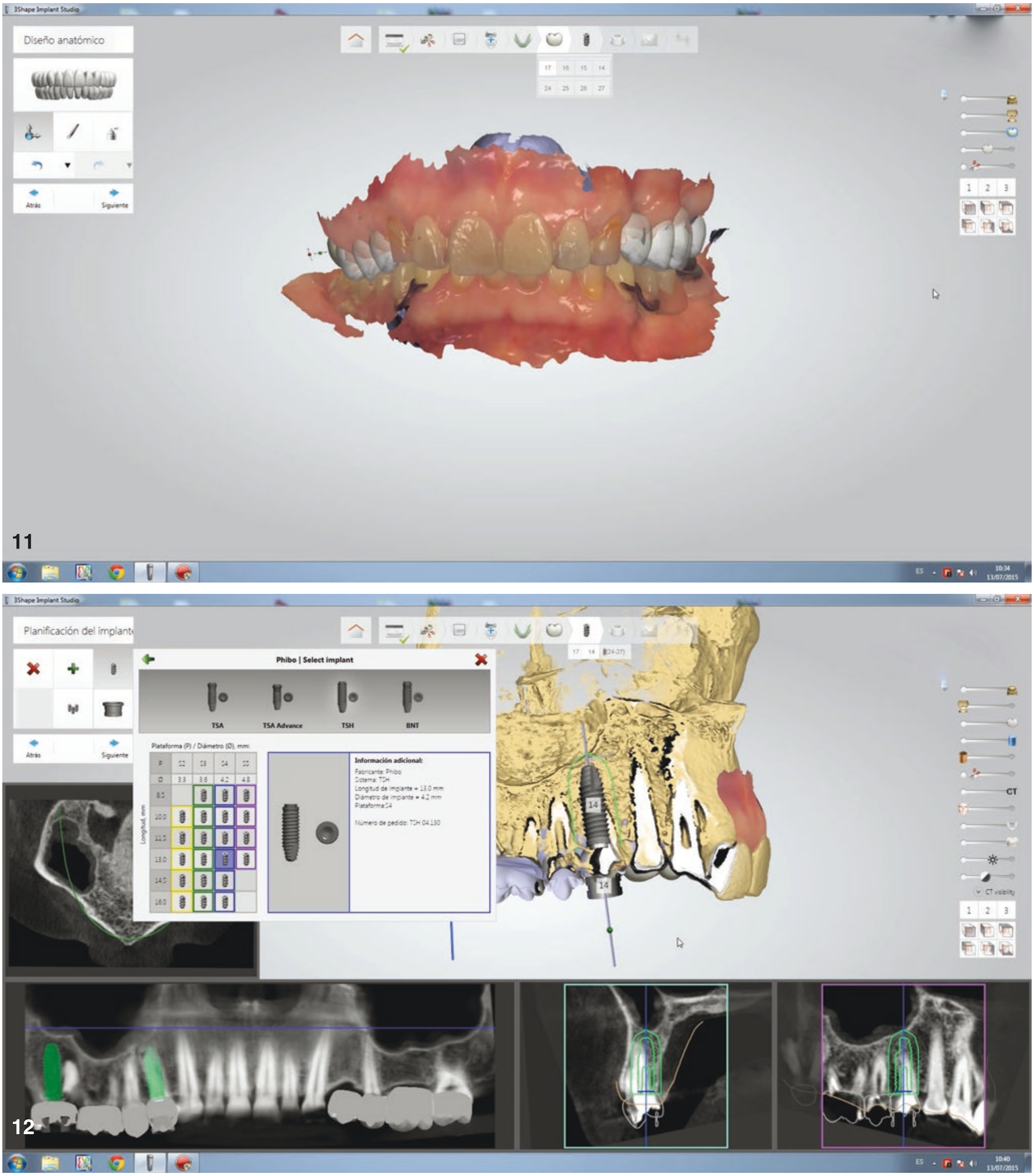

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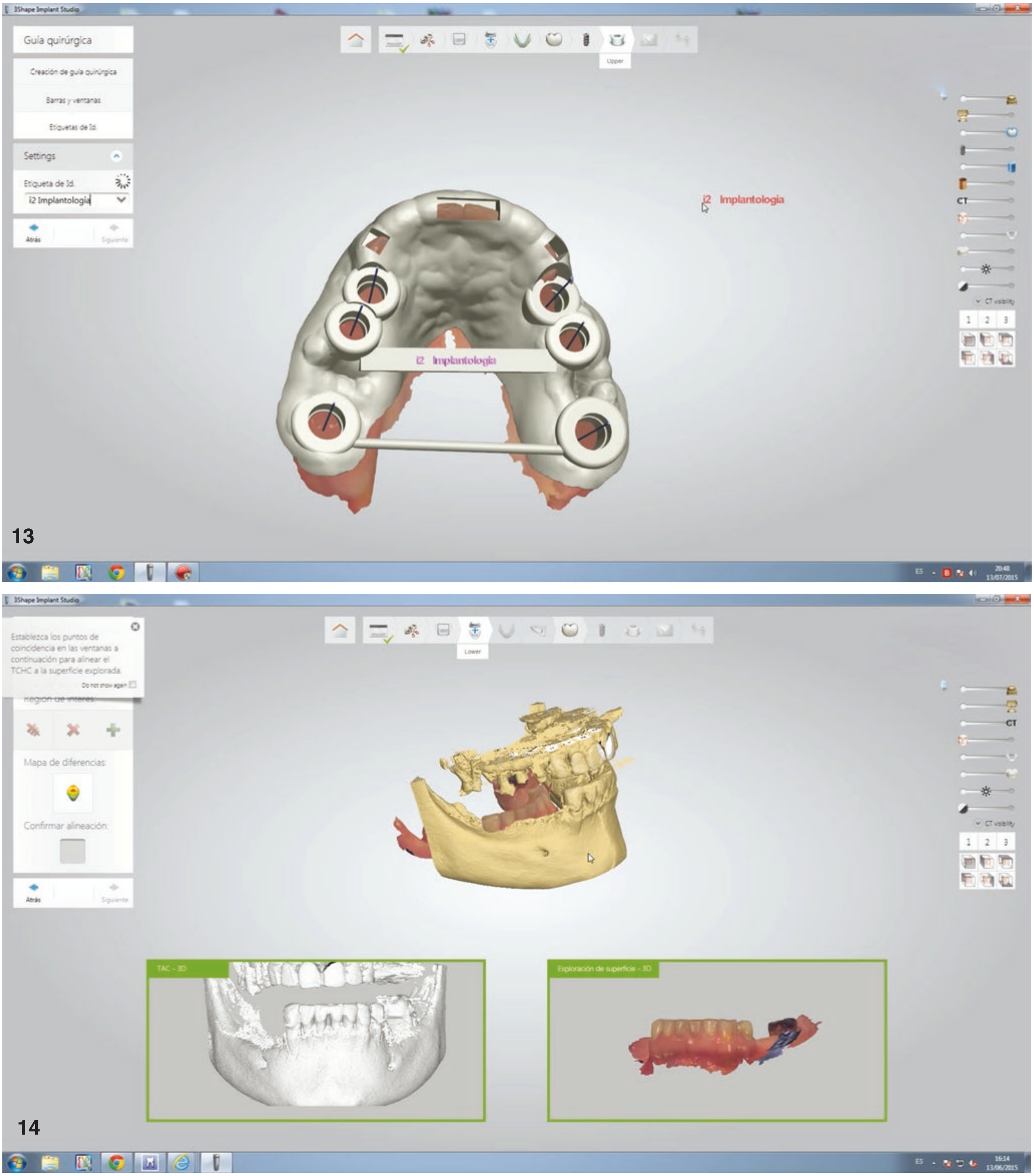

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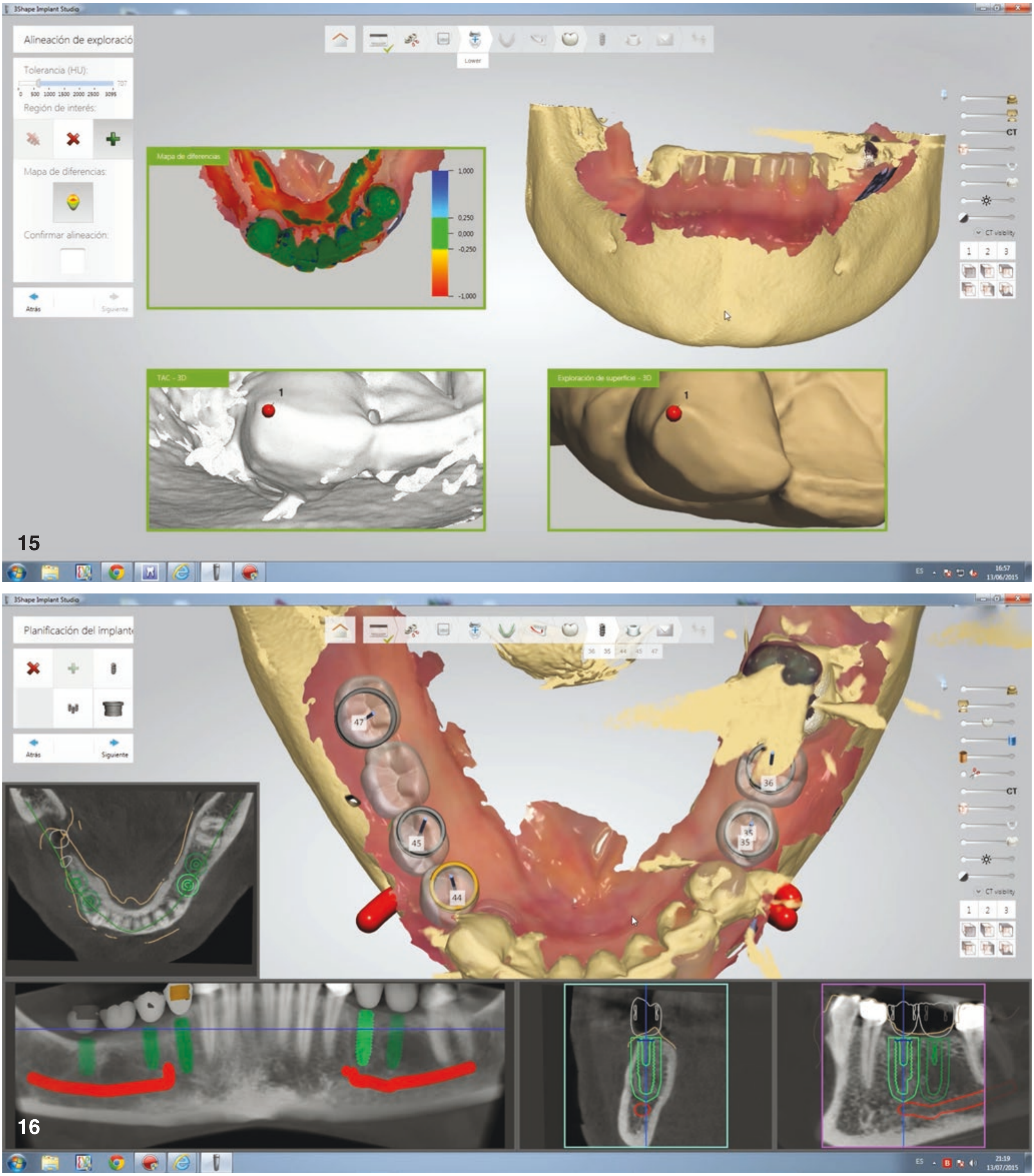

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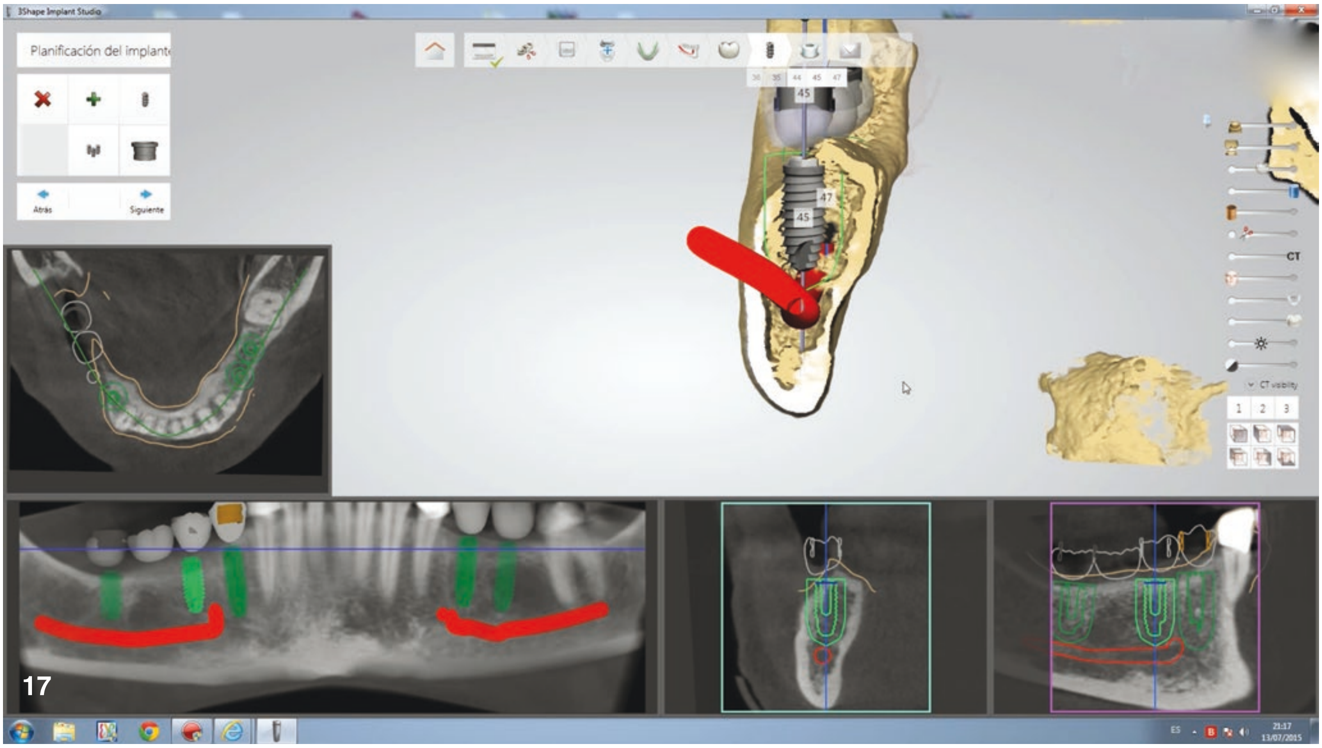

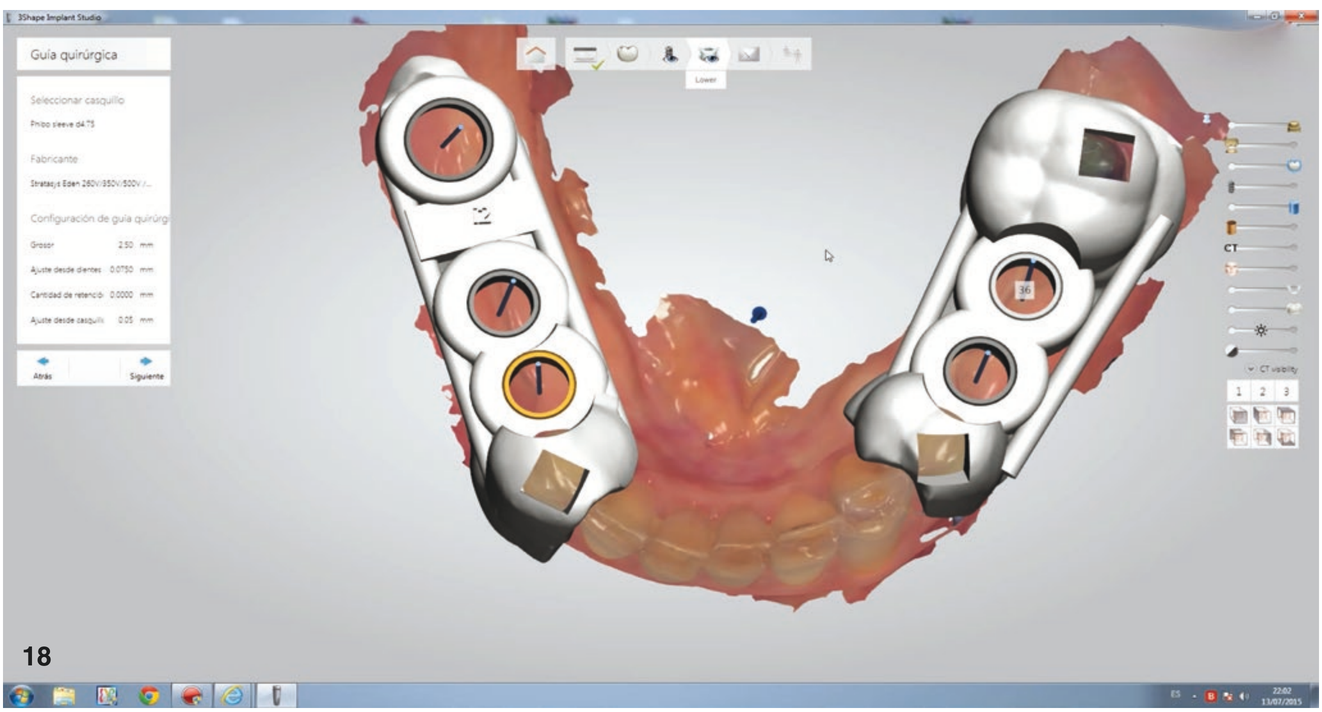

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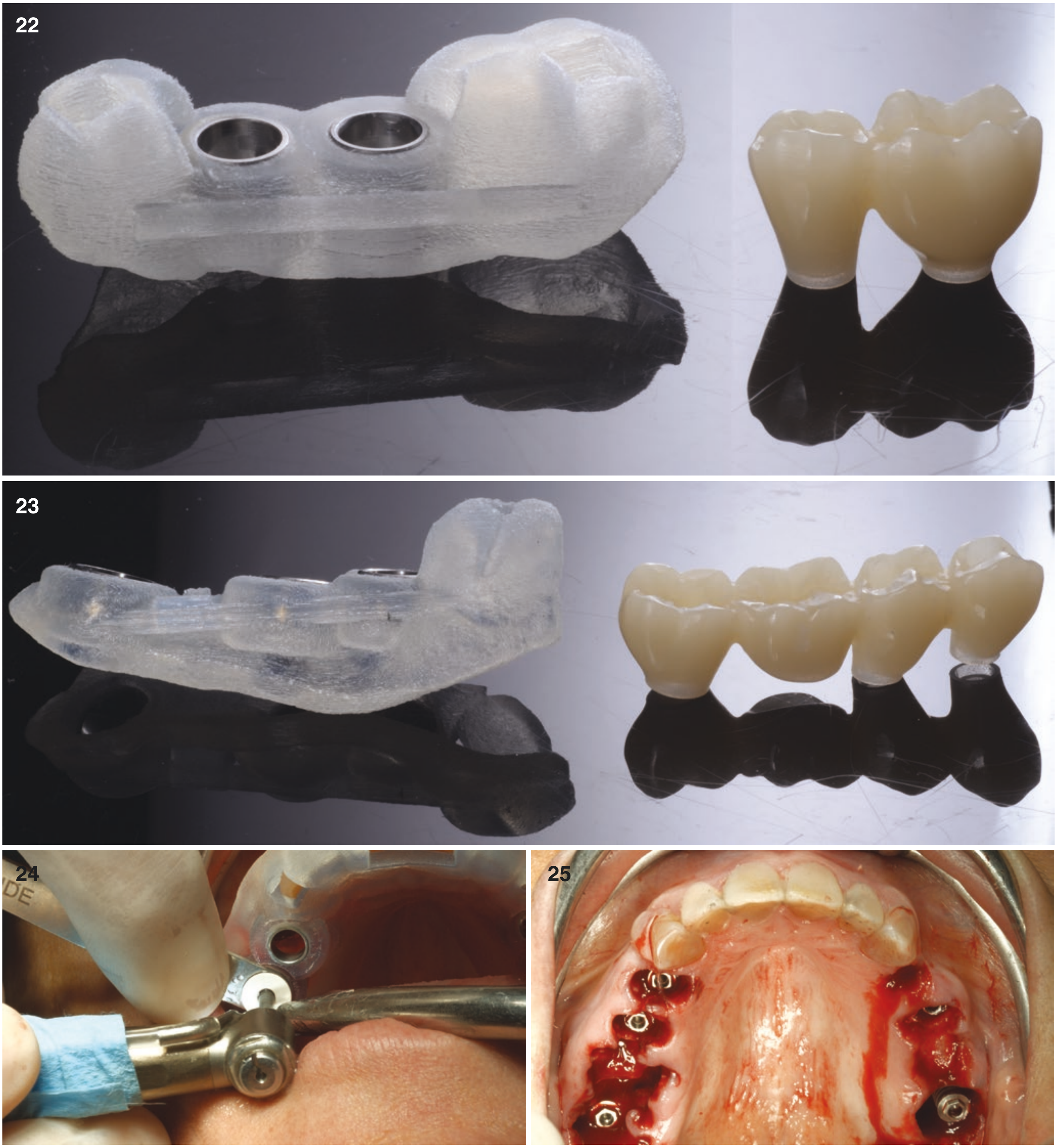

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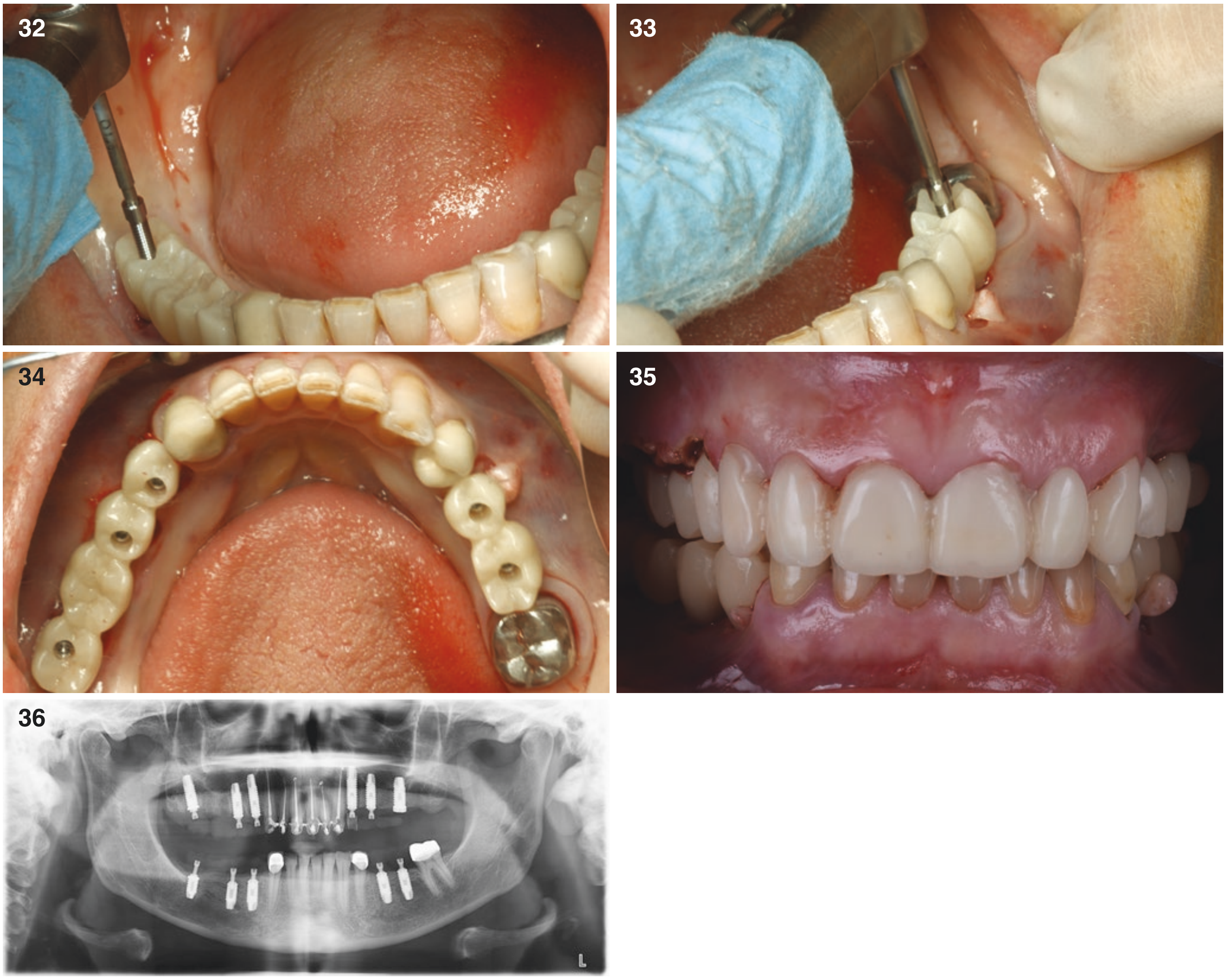

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Table 1 Authors' classifications of indications and contraindications to immediate loading

Indications to immediate loading	
Patient's desire to reduce the overall treatment time	
Psychological factors (preservation of function and esthetics)	
Adequate oral hygiene standards	
Good bone quality	
Adequate primary stability (insertion torque ≥35 Ncm)	
Traumatic tooth dislocation/fracture in the esthetic area	
Edentulous mandible	
Recently edentulous maxilla	
Partially dentate mandible	
Partially dentate maxilla	
Single edentulism in the mandible	
Single edentulism in the maxilla	
Contraindications to immediate loading	
Local	*Systemic*
Absence of primary stability	Drug and alcohol abuse
Severe atrophy of the jaws	Radiotherapy to the head and neck
Need for extensive bone grafting procedures	Antiblastic chemotherapy
Severe maxillomandibular skeletal discrepancy	Severe chronic renal or liver disease
Heavy smokers	Uncontrolled diabetes (*)
Uncontrolled bruxism	Recent infarction
Severe periodontal disease	Immunocompromised status
Long-term edentulism (*)	Pregnancy at the time of evaluation
Local acute infection (*)	Bleeding disorders
Lack of posterior occlusal support	Hemophilia

Among contraindications, those marked with the asterisk (*) are to be considerate relative

for implant placement, a staged augmentation should be considered every time there is the risk of positioning a suboptimal restoration, larger than normal, with an unnatural emergence profile.

Contraindications to Immediate Loading

Contraindications to immediate loading could be gathered into local or systemic and into absolute or relative. Among local contraindications, there is the lack of adequate adjacent bone levels. The immediate loading of implants in such sites without preliminary reconstructive surgery may compromise esthetics and phonetics. Poor density bone is now considered a relative contraindication since it can be addressed with modified implant macrostructure and surgical technique.

Excessive smoking or para-functional habits (severe bruxism or clenching habits, poor oral hygiene, and local inflammation) could be considered as relative or transient contraindications. Some authors reported successful outcomes also in heavy smokers and bruxers (Cannizzaro and Leone 2003). An extensive bone grafting at the time of immediate loading has been discouraged. It is better to avoid major grafting procedures and to limit the use of grafts to fill small bony defects and dehiscence (Shibly et al. 2010; Vijayanathan et al. 2013). In fact, additional vascularization is required when reconstructive procedures are performed and the relative movement of the loaded implants might compromise the successful healing and integration of the graft. However, some authors suggested that maxillary sinus membrane elevation with simultaneous placement and immediate loading of implants show predictable results after 2 years of functional loading (Cricchio et al. 2014).

Immediate loading is not recommended in patients with lack of posterior occlusal support, especially when they plan to rehabilitate the anterior area which would be subjected to unfavorable shearing and non-axial forces. General contraindications to surgery and some systemic conditions must be considered before any implant treatment. Neoplasia (followed by chemotherapy or previous irradiation in the neck/head area), hematological malignancy, coagulation disorders, severe cardiovascular diseases, or severe osteoporosis treated with intravenous amino-bisphosphonates should be considered as absolute contraindications.

The question whether diabetes mellitus, particularly non-controlled diabetes, should be considered a contraindication to implants or not is a really debated one. In fact, until recently, diabetes remained a relative contraindication for implant surgery because of delayed wound healing, microvascular disorders, and impaired response to infection. However, patients with diabetes lose more teeth than healthy patients, and they would be recommended to implant-retained rehabilitations more often. Most available data regarding diabetes and dental implants come from case series, and there is a lack of randomized clinical trials comparing the outcome of dental implants in diabetic and in healthy patients. Furthermore, only a few studies specify whether it was followed by a delayed or an immediate loading protocol.

According to the 2016 systematic review by Moraschini and colleagues, the rate of implant failure was not higher for diabetic subjects (Moraschini et al. 2016). On the contrary, the 2016 review by Annibali and colleagues suggested an increased risk of implant failure during the osteointegration period in patients with diabetes. In 2017, Al Amri published the first study comparing the clinical and radiographic status around immediately loaded and conventional loaded implants placed in 108 patients with type 2 diabetes mellitus (Al Amri et al. 2017). The authors reported a 100% survival and success rates for both groups at a 24-month evaluation. It must be remarked that patient selection was restricted to non-smokers and well-controlled diabetics. Immediate loading in diabetic patients is a reliable procedure in the hands of an experienced surgeon as long as some requirements are provided: patients should present a strict metabolic control; antibiotic prophylaxis and chlorhexidine mouth-rinse are

Fig. 8 (**a**) Frontal clinical view; there exists a grade 3 mobility in the upper right lateral incisor. (**b**) Panoramic radiograph shows periodontal bone loss beyond tooth apical third. (**c**) Atraumatic tooth extraction, trying to avoid damage of the socket walls. (**d**) After tooth extraction, an adequate maintenance of soft tissue architecture is appreciated. (**e**) Implant bed preparation with a sequence of drills and osteotomes. (**f**) Frontal view after Phibo® 4.2 × 13 mm implant placement. (**g**) Implant stability quotient was measured with Ostell® mentor device, obtaining an ISQ value of 62 (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**h**) Occlusal view after implant placement. There is a narrow space between implant and socket walls. (**i**) A prosthetic abutment is connected. (**j**) A temporary plastic abutment was adapted. (**k**) The height was reduced to adapt the temporary crown. (**l**) A prefabricated resin crown was lined with autopolymerizable resin to the temporary abutment. The liner excess was removed, and the crown was adapted and polished to provide a good emergence, before cementing it. (**m**) Clinical view of the temporary crown of upper right lateral incisor in place. (**n**) Occlusal view of soft tissue aspect at 3 months in the moment of definitive abutment connection. (**o**) Frontal view of the good soft tissue contour and papilla architecture. (**p**) Frontal view of the definitive crown delivery. (**q**) Panoramic radiograph after definitive restoration. (**r**) Good esthetic result with adequate papilla at 6 month control

Fig. 8 (continued)

Fig. 8 (continued)

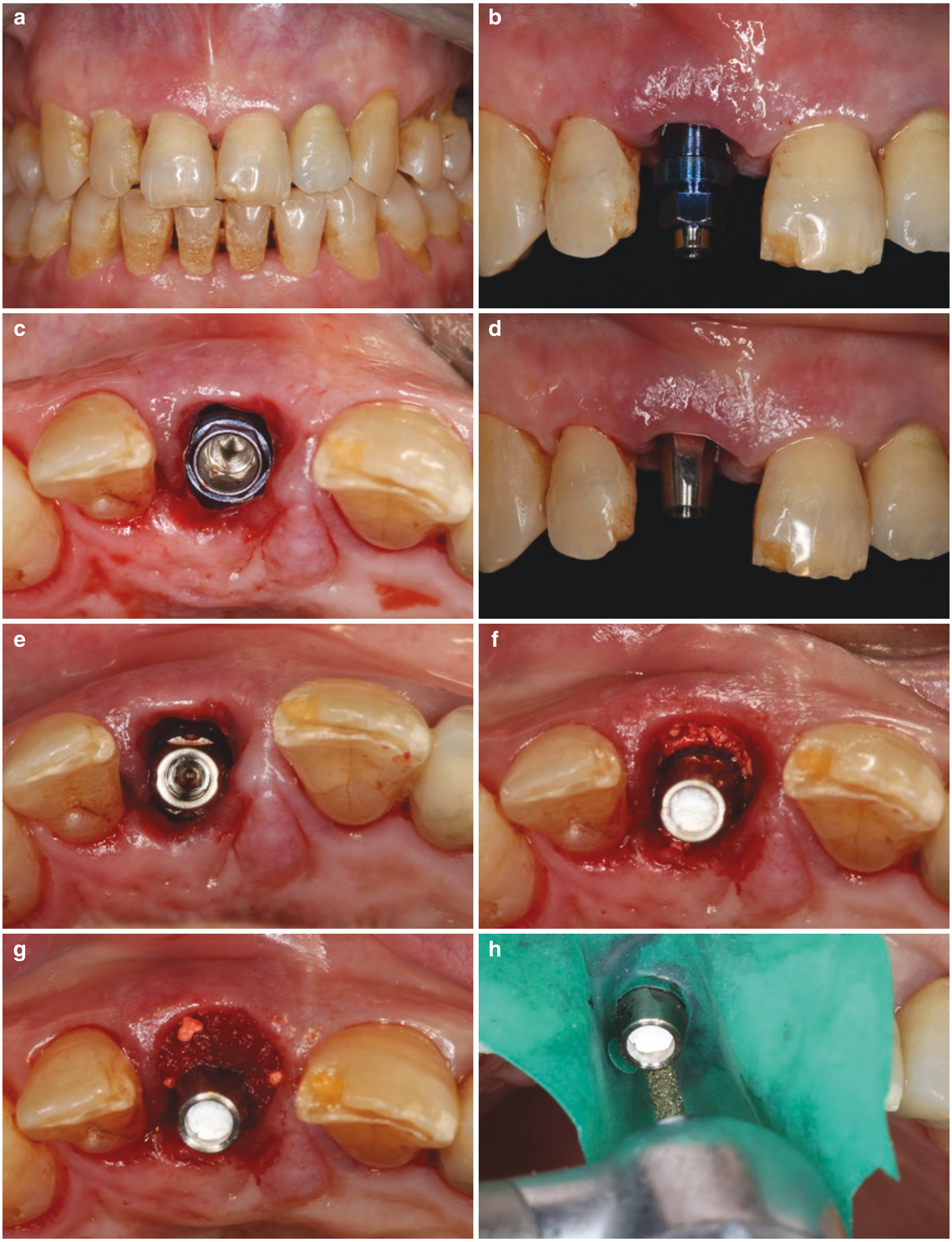
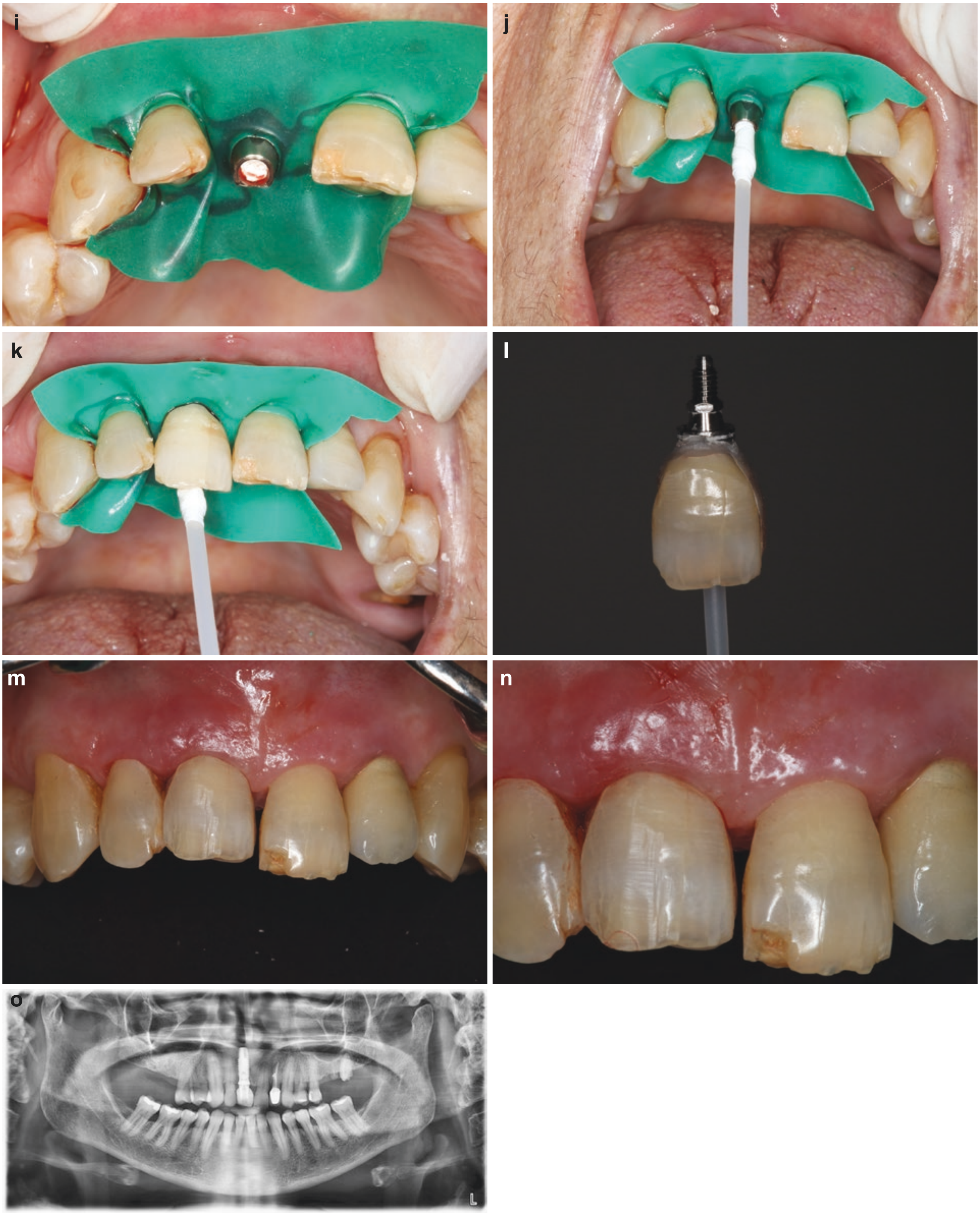


Fig. 9 (**a**) Initial frontal view of maximum intercuspidation, a slight redness of mucosa at the level of the upper right central incisor is perceived. (**b**) Post-extractive implant placement to replace an upper right central incisor fractured (Phibo® TSA., Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**c**) Occlusal view of installed implant. (**d**) Temporary prosthetic abutment screwed to implant connection. (**e**) Occlusal view of the gap between implant surface and buccal bone plate. (**f**) The gap was filled with deproteinized bovine bone mineral. (**g**) A collagen plug was placed above the biomaterial as barrier. (**h**) The prosthetic abutment was cut and reduced to avoid occlusal interferences. (**i**) Occlusal view of the prosthetic abutment after its modification. (**j**) A large plastic tip was introduced into the prosthetic abutment hole to avoid resin entry. (**k**) The own tooth of the patient was used to prepare a temporary prosthesis. A hole was prepared at palatal surface of the crown to ensure the corrected fit of the prosthetic abutment. A composite resin was used to fix the tooth crown to the prosthetic abutment. (**l**) A screw-retained temporary crown was prepared with the patient's tooth. (**m**) Frontal view of the temporary crown in position. (**n**) Detail of the restoration and soft tissue at prosthesis delivery. (**o**) Radiograph image of implant with temporary crown



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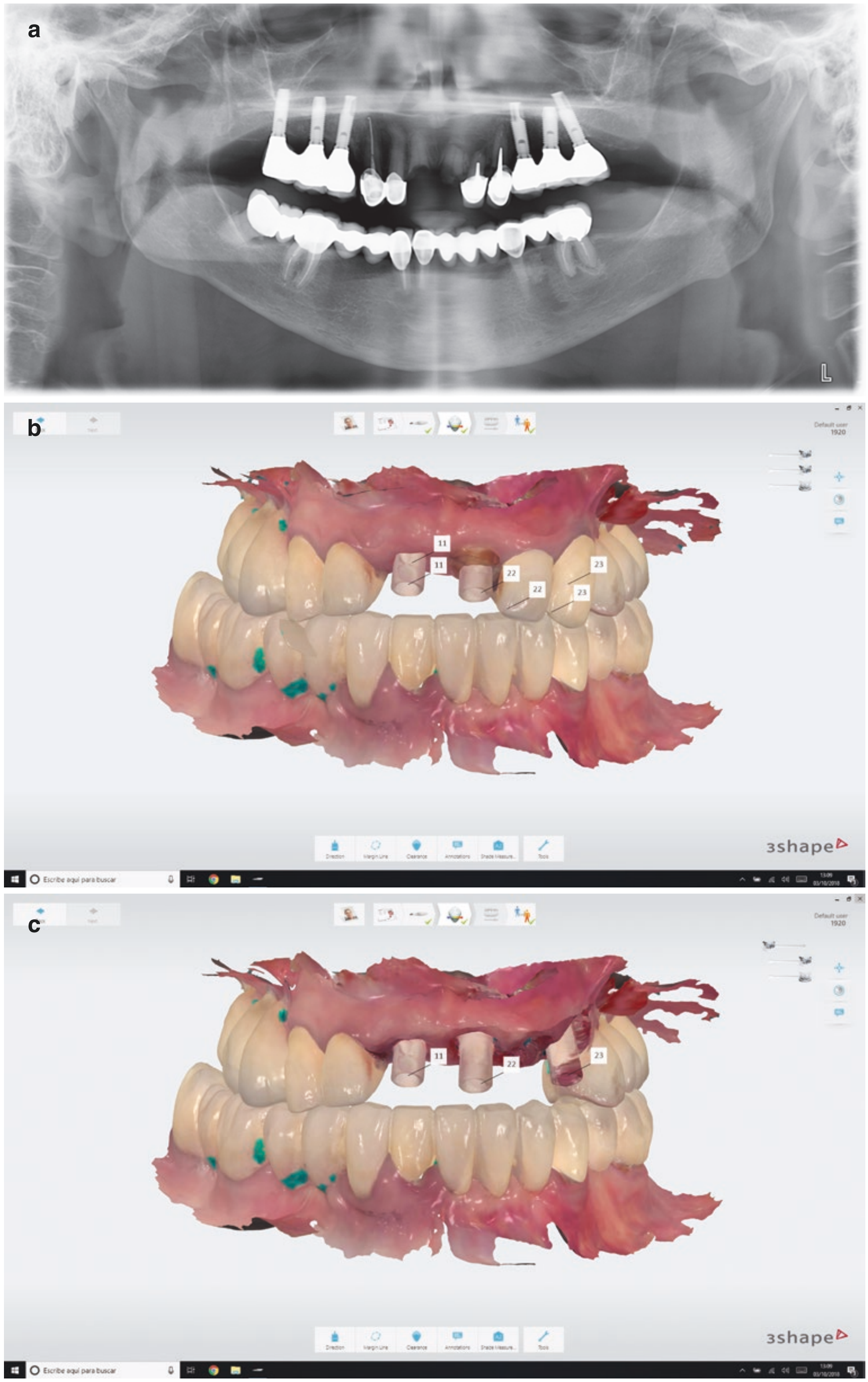

Fig. 10 (**a**) Panoramic radiograph showed the destruction of central incisors and failure root canal treatments at the level of upper left lateral incisor and canine. (**b**) CBCT and intraoral scanning data was merged in planning the implant position and CAM immediate restoration confection using patient's own fixed prosthesis as guide. (**c**) The emergence of implants was defined through computer-aided surgical planning. (**d**) Immediate restoration after implant placement. (**e**) Postoperative panoramic radiograph

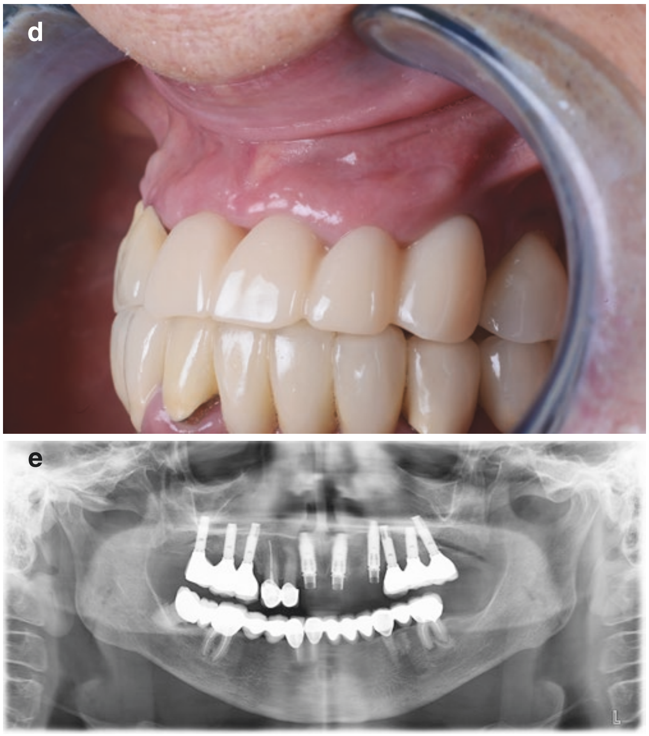

Fig. 10 (continued)

recommended; and the provisional prosthesis should have an optimal contour, a narrow occlusal table, and complete disocclusion in eccentric movements.

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Diagnosis and Planning in Immediate Loading: Implant Selection

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Abbreviations

IL Immediate loading

Take-Home Message
Primary stability depends on bone quality and quantity, surgical technique, and implant selection. Implant features such as dimensions and micro- and macro-design might influence immediate loading success. Appropriate selection of implant type, number, and position must be part of the surgical diagnosis and treatment planning workflow.

Introduction

Despite the increasing patients' desire for immediate prosthetic loading of implants, several factors must be taken into account before pursuing the IL protocol. Success of dental implants depends mainly on primary stability which is defined as the absence of movement after surgical implant placement, and it is often related to insertion torque (Cannizzaro et al. 2007). Primary stability is highly influenced by bone quality and quantity, surgical technique, and implant design (Meredith 1998). The implant design could be described in its micro- and macro-features: macro-design includes thread pitch, body shape, thread design, and the collar emergence profile, while micro-design refers to the surface morphology and characterization. In order to maximize the engagement to the bone and the primary stability, the implant body has been modified with different measures such as the introduction of self-tapping threads at the apical portion of the implant, increased implant diameter and length, modification of number of threads, type of threads, and taper of the body of the implant.

In general, the number, size, characterization, and distribution of implants should be based on the implant-prosthodontic plan, arch form, and available bone quality and quantity, regardless of the loading protocol. However, implant selection in IL represents one of the most important clinical challenges due to the primary stability requirement.

The introduction of digital implant planning with dedicated software has eased this step in a multifold way: the clinician has the chance to simulate the surgical act trying implants differing in shape, diameter, and length.

Implant Design

Macro-design

Implant macro-geometry may enhance forces transmission to the bone preventing marginal bone loss. Szmukler-Moncler et al. (1998) indicated that micromotion at the interface beyond 150 μm should be avoided, as this could cause the wound to undergo fibrous healing instead of osseous regeneration. In general, all implants fall into one of two large categories: tapered or cylindrical/parallel walled. Tapered implants were introduced for post-extractive sites with poor bone quality. In a recent randomized split-mouth clinical study, tapered and cylindrical implants were placed using the same implant protocol in ten patients with edentulous jaws (Torroella-Saura et al. 2015). The authors reported greater implant primary stability and less marginal bone loss for tapered implants. One of the falls of tapered implants is that they are more difficult to seat in cortical bone. The threaded implant was designed to avoid micromotions at the early stages of healing. Each thread pushes the bone laterally with increasing diameter generating a wedge effect and condensing the bone as the osteotomes would do. Furthermore, threaded

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implants are generally recommended for IL because they display greater bone-to-implant contact in comparison to implants with cylindrical design.

The collar geometry might play a role as well. It has been suggested that implants with a shorter polished smooth collar are more effective in decreasing marginal bone loss (Calvo-Guirado et al. 2015). A smooth-neck implant results in reduced plaque accumulation and, thus, lower inflammation; however, finite element analysis investigations revealed high stress concentrations in the cervical and apical area of the implant (Sadrimanesh et al. 2012). Therefore, marginal bone loss might be also attributed to unfavorable stress distributions at the coronal portion of the implants.

Micro-design

Surface characterization and topography have been also related to implant stability and osteo-integration. In vivo experiments revealed that rough-surface dental implants dramatically enhanced bone-implant interface and lowered the rate of bone loss compared with smooth surfaces (Sato et al. 2014). The larger the surface area, the greater the mechanical connection to the surrounding bone (Romanos et al. 2002). The quality and degree of surface characterization (sandblasting, acid etching, plasma spraying) promote osteogenesis by enhancing the proliferation and metabolic activity of osteoblasts. In poor bone quality sites, implants with an acid-etched surfaces can achieve a significantly higher bone-to-implant contact compared to implants with a machined surface.

The systematic review by Koodaryan showed that insertion of implants with rough and rough-surfaced micro-threaded neck implants led to less marginal bone resorption if compared to machined-neck implants (Koodaryan and Hafezeqoran 2016). Still, some authors reported no difference in terms of marginal bone loss and survival rate among different implant designs. Gilbert and colleagues reported the outcomes of a randomized controlled clinical trial aiming to assess whether a coronal micro-threaded design and an internal abutment connection affected crestal bone loss in immediately loaded implants (Glibert et al. 2018). Each patient received four implants in the upper edentulous jaw, each one with a different morphology. The authors found that crestal bone remodeling was not affected by the implant-abutment connection and the presence of micro-threads. In fact, bone remodeling is a multifactorial process and might be more dependent on other factors than implant design itself. For example, of utmost importance is a homogenous distribution of stresses within each implant and among multiple splinted implants.

Implant Length and Diameter

Implant diameter and length have been qualified as key factors in IL procedures, since they directly influence the primary stability of dental implants. However, there is no exhaustive indication regarding optimal implants' length and diameter for IL. Being general, using the longest possible implant in each site is a wise approach (Tealdo et al. 2011; Kinsel and Liss 2007). In fact, implants' dimensions are supposed to compensate for diminished bone quality. Increased length is important especially in extraction sites to engage apical bone and to increase the area of bone compression where under-preparation of the site is employed. The authors of the 2014 5th ITI Consensus Conference stated that IL of micro-textured dental implants with one-piece fixed interim prostheses in both the edentulous mandible and maxilla is as predictable as conventional loading (Gallucci et al. 2014). Most of the included studies reported a minimal implant length of ≧10 mm; therefore, there is no consensus on what would happen with shorter implants. In the edentulous patient, most authors consider 10 mm to be the minimum adequate implant length to predictably perform IL with full-arch prosthesis in the maxilla (Peñarrocha-Oltra et al. 2014).

Comparative stress analysis suggested that increased implant length might decrease the stress distributed to maxillary bone or at least that it might produce a more uniform transmission of forces (Gao et al. 2014). In the posterior mandible with poor bone quality, implants' diameter exceeding 4 mm and length exceeding 12 mm have been suggested as optimal in finite element analysis models (Li et al. 2011): increased diameter and length reduced the stress transmitted to the bone under both axial and bunco-lingual loads.

In the case of single edentulism in the anterior region, the presence of limited space, inter-radicular proximity, and high esthetic need represent an indication for IL with narrow-diameter tapered implants. This implant configuration also helps in optimizing the emergence profile of the restoration and prevents crestal bone loss (Kolinski et al. 2018). If placement of standard dental implants is prevented by local contraindications or by patients' desire to avoid bone augmentation procedures, short implants might represent an alternative. There is increasing evidence of the predictability of IL of short dental implants in fixed single- and fixed multiple-unit prostheses (Anitua et al. 2018). Splinting of short dental implants is recommended in order to minimize lateral forces and improve stress distribution. Since the long-term evidence on IL with short implants is scarce, careful case selection is important to avoid detrimental occlusal and eccentric loads that could lead to early implant failures.

Implant-Abutment Connection

The *platform switching* concept is based on the use of a narrower abutment in relation to implant diameter aiming to reduce peri-implant bone resorption (Lazzara and Porter 2006). The creation of a horizontal space allows harboring the chronic inflammatory infiltrate far from the crestal bone. In this coronal groove, the soft tissues are free to expand, thus promoting the formation of a well-represented amount of protective keratinized gingiva. However, recent studies have suggested that platform switching did not prevent bone remodeling in patients with a thin biotype (Puisys and Linkevicius 2015).

Abutment height might also influence bone resorption (Piattelli et al. 2003). In fact, the relative position of the micro-gap (implant-abutment interface) to the bone is important to avoid bone remodeling: a deep micro-gap, at the level or below the bony crest, results in a displacement of the chronic inflammation deep into the bone.

Blanco and co-workers recently published the results of a randomized clinical trial assessing the effect of different abutment heights on early implant healing (Blanco et al. 2018). The authors showed greater bone resorption in implants loaded with short abutments in comparison with long abutments.

The 2018 systematic review by Sanz-Martín reported that the abutment macroscopic design, surface topography, or manipulation did not have a significant influence in soft tissue inflammation; still, titanium abutments showed greater bleeding on probing than zirconia abutments (Sanz-Martín et al. 2018). The authors attributed this outcome to zirconia less plaque retention, compared to titanium, due to the surface properties of this material. However, the authors did not include a stratified analysis on implant sites: it could be speculated that the sample representing titanium abutments was mostly related to posterior implants as it is customary to prefer zirconia in the anterior area which is also associated to lower inflammation rates than posterior regions.

Implant Number and Position

The main indication for IL is the total edentulism in a patient who is unable to tolerate a removable prosthesis. Possible rehabilitations include implant overdenture, implant Toronto bridges, implant full-arches, and all-on-four rehabilitations. Each prosthetic protocol comes with a minimum recommended number of implants. Great part of the literature strongly support the placement of more implants to decrease the peri-implant stress at each site. However, this consideration might not hold true for every clinical situation. Since there are scenarios in which adding one or more implants will not reduce the amount of stress at the bone-implant interface, planning a proper treatment scheme is fundamental. Implant number for IL in a totally edentulous patient depends on the jaw (upper or lower), on the residual bone quality and quantity, and on the arch shape.

The suggested guidelines for immediate full-arch restorations are reported in Table 1.

The main recommendation is to achieve a uniform forces distribution along the alveolar arch, irrespective of the number of placed implants, and to minimize the need of cantilevers with the use of distally tilted implants (Bergkvist et al. 2009; Tealdo et al. 2011).

Table 1 Suggested guidelines for immediate loading complete edentulous fixed prostheses

	Maxilla	Mandible
Implant number	4–12	2–10
Implant position	2,4,5 (lateral incisor, first premolar, second premolar)	At least one in the anterior region and one in each posterior region

The number of implants used to support a fixed prosthesis varied from 2 to 10 in the mandible and 4 to 12 in the maxilla. This difference is due to the different bone composition in the upper and in the lower jaw. The great amount of cortical bone in the mandible allows to keep implant number lower. Predictable outcomes for immediate full-arch prostheses were achieved with an adequate number of positioned implants, at least six (Bergkvist et al. 2009; Strietzel et al. 2011). However, no relationship between the number of implants and the prosthetic success was found (Balshi et al. 2005). The all-on-four concept was introduced in 2003 and basically refers to the placement of two axially loaded anterior implants and two tilted ones in the posterior zone (Malo et al. 2003). The tilting of distal implants should allow for a reduction in the prosthetic cantilever length, resulting in decreased peri-implant bone stress (Horita et al. 2017). Long-term data on fixed prostheses retained by four implants in the edentulous mandible showed similar outcomes of those retained by more implants (Gallucci et al. 2004). The recent systematic review by Soto-Penaloza and co-workers shed light upon the therapeutic indications, surgical procedures, prosthetic protocols, patient satisfaction, and main complications associated to the all-on-four treatment concept (Soto-Penaloza et al. 2017). The authors reported a success rate ranging between 94.8% and 100% at implant level; the survival rate ranged between 97.6% and 100%.

For fixed partial prosthesis (PFP), two strategies can be adopted: multiple single-tooth implants or PFP on two (or more) implants. Consecutive single-tooth rehabilitation procedure requires extremely detailed treatment planning due to limiting anatomic situations regarding inter-implant distances to be respected (Tarnow et al. 2000; Degidi et al. 2008).

In fact, inter-implant bone resorption is increased by reduced distance between two dental implants; this could result in the excessive loss of papillae and poor esthetic outcome (Mankoo 2008; Testori et al. 2008). Prevention of inter-implant marginal bone resorption can be ensured by means of specific dental implant designs such as the introduction of small diameter implants and/or the platform switching connection. However, it is frequently impossible to replace each missing tooth (Canullo et al. 2009). A more reliable treatment option would be a fixed partial denture supported by a reduced number of implants. The original recommendation was to achieve prosthetic unit-to-implant ratio of at least 1.4 in the maxilla and 1.5 in the mandible

(Degidi and Piattelli 2003) and to increase initial stabilization by avoiding tapping of the osteotomy site and by underdrilling the apical width of the osteotomy (Calandriello et al. 2003). Moreover, provisional restorations should be fabricated with light occlusal contact or left out of occlusion (Bogaerde et al. 2003; Malo et al. 2003).

Treatment Planning for Immediate Loading in the Edentulous Jaws

Mandible

Jensen suggested that the lower edentulous mandible could be described by three different features: the presence of posterior bone above the inferior alveolar nerve canal; the presence of bone above the mental foramen; and the interforaminal length (Jensen 2014). Accordingly, four classes could be identified:

- Class A: Enough bone in the molar region above the inferior alveolar nerve canal; sufficient bone above the mental foramen; enough interforaminal length. Surgical recommendation: four to six axial implants, two in position of the first molars and two to four in the interforaminal region (Fig. 1).
- Class B: No bone presence in the posterior areas; sufficient bone above the mental foramen; enough interforaminal length. Surgical recommendation: four implants, two anterior axial implants and two posterior tilted implants. The entrance point of the two posterior implants is above the mental foramen with a 30° angulation to save the nerve loop and reduced the cantilever length. All-on-four protocol (Fig. 2).
- Class C: No bone presence in the posterior areas. No bone presence above the mental nerve. Slightly reduced interforaminal length. Surgical recommendation: four implants, two anterior axial implants and two posterior tilted implants. The entrance point of the two posterior is forward the mental foramen with a 30° angulation. All-on-four protocol (Fig. 3). If the apexes of the posterior implants are going to stay very close to the apexes of the axial implants, or even in risk of contact, due to the interforaminal reduced length, it is possible to tilt the anterior implants medially, in the same direction as the posterior implants.
- Class D: No bone presence in the posterior areas or above the mental foramen. Reduced interforaminal length. This mandible corresponds to Cawood and Howell classes V–VI. Surgical recommendation: three implants, one anterior axial implant in the midline or close to it and two posterior tilted implants. As an alternative, four interforaminal axial implants can be placed. The inferior alveolar nerve is commonly dehisced and is usually on top of the ridge, where it can easily be reflected with a little manipulation. The implant site preparation can then begin in the foramen concavity itself to improve the A/P spread (Fig. 4).

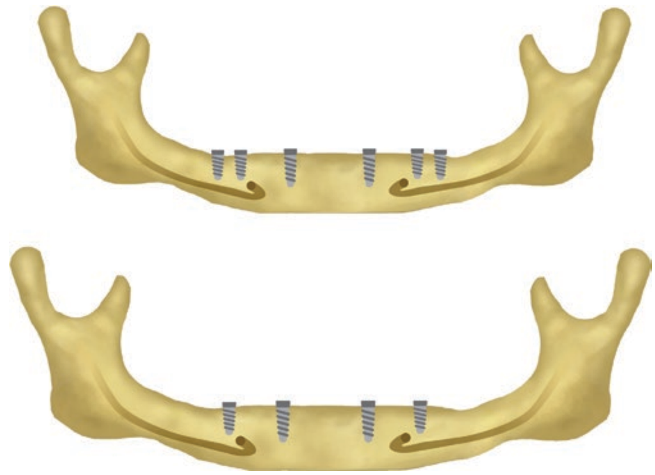

Fig. 1 Class A mandible: The volume of alveolar ridge is sufficient to place from four to eight implants of variable length. Short posterior implants could be placed above the inferior alveolar nerve canal in first/second molar positions. Anterior implants are usually placed within interforaminal space, and the implants could be spaced 15–25 mm around the arch without cantilever, when posterior implants are placed in the first/second molar locations

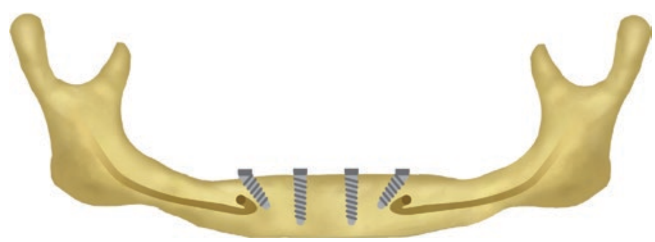

Fig. 2 Class B mandible: The volume of bone above the inferior alveolar nerve canal allows short implant vertical positioning posterior to the foramen. If posterior sites are forbidden, implants could be placed slightly posterior to the foramen by angling the implant forward to avoid the nerve (implant angles forward at a 30-degree). The anterior implants could be placed perpendicular to the ridge and spaced equidistantly

Fig. 3 Class C mandible: Vertical bone above and posterior to the foramen is not sufficient to place entry points of straight or angled implants in the first premolar zone (Jensen et al. 2011). A cantilever from 10 to 15 mm could be required (Oliva et al. 2012). The central implants could be angled at 30 degrees toward the midline and extend apically just above the inferior border in a V formation (Jensen et al. 2014). This implant distribution resulted in a reduced anterior/posterior spread (from 10 to 12 mm) and in an inter-implant span between 30 and 40 mm (Jensen et al. 2009)

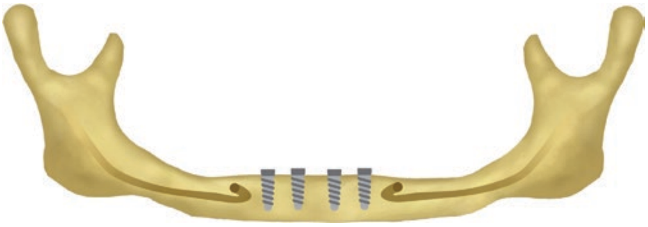

Fig. 4 Class D mandible: Because the bone is usually highly dense but extremely resorbed, the use of four axial and short implants is an option. Usually, the inferior alveolar nerve is on top of the ridge, so that the cantilever in the definitive restoration should be limited to 10 mm, as the A/P spread resulted between 8 and 12 mm

Maxilla

According to Bedrossian et al. (Bedrossian et al. 2008), the maxilla can be divided into three zones: zone 1, the premaxilla; zone 2, the premolar area; and zone 3, the molar area (Fig. 5). The clinician should determine the availability of bone in all three zones. Cone beam computed tomography can be used to determine the amount of bone in these zones as well as in the zygomatic arch, in both horizontal and vertical dimensions. Moreover, any pathology in these areas, as well as in the maxillary sinuses, needs to be verified preoperatively.

- Bone presence in zones 1, 2, and 3: traditional four to six axial implants (Figs. 6 and 7)
- Bone presence in zones 1 and 2: four implants – two anterior axial implants and two posterior tilted implants guided by the anterior maxillary sinus wall. All-on-four protocol (Fig. 8)
- Bone presence only in zone 1: two anterior axial implants and two zygomatic implants bilaterally in molar/premolar area. All-on-four hybrid protocol (Fig. 9)
- Insufficient bone in all zones: four zygomatic implants. Quad zygoma or all-on-four zygoma (Fig. 10)

In the presence of a narrow bone ridge, it is necessary to put the implants with a palatal position in the anterior or premolar zones. With this approach, it is possible to achieve good primary implant stability and overcame the deficiency of a thin marginal crest (less than 4 mm wide). The placement of implants palatal to the alveolar crest in the maxilla allows maximum use of the available bone in patients with severe horizontal bone resorption, reducing patient morbidity compared to conventional augmentation procedures (Peñarrocha et al. 2009) (Fig. 11a, b).

A representative case of a patient with mandible Class B and maxilla with bone in areas 1 and 2 treated with the all-on-four approach was shown in Figs. 12a, b, 13a–k, 14a–f, 15a–c, and 16a–g.

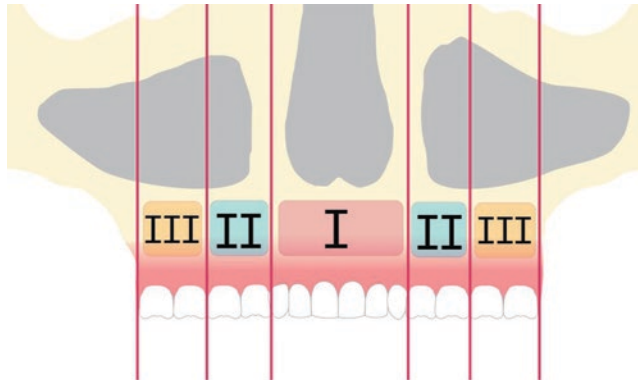

Fig. 5 Division of the maxilla in three zones: I, premaxilla; II, premolar; III, molar

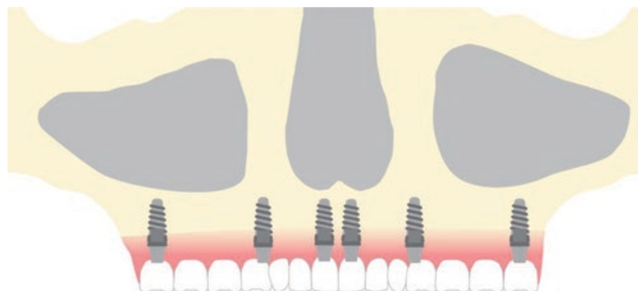

Fig. 6 Presence of bone in zones 1, 2, and 3. Six axial implants

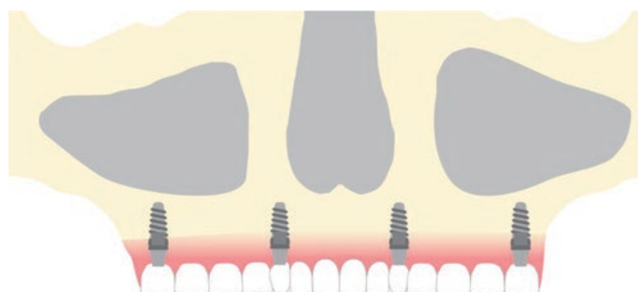

Fig. 7 Presence of bone in zones 1, 2, and 3. Four axial implants

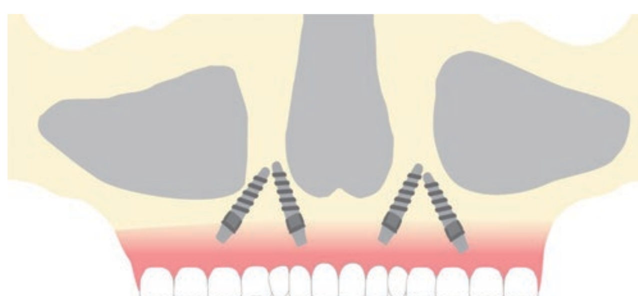

Fig. 8 Presence of bone in zones 1 and 2. All-on-four

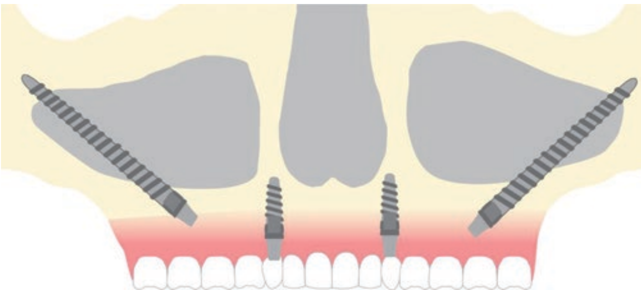

Fig. 9 Presence of bone in zone 1. All-on-four hybrid

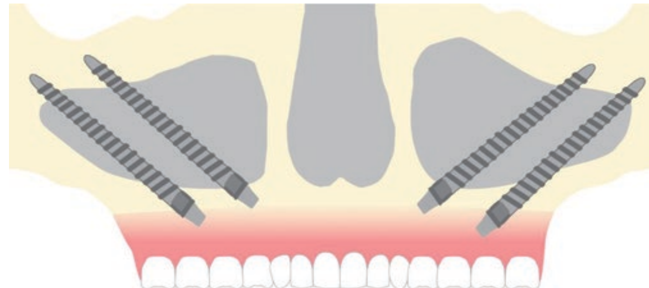

Fig. 10 No bone presence in zone 1, 2, or 3. All-on-four zygoma or quad zygoma

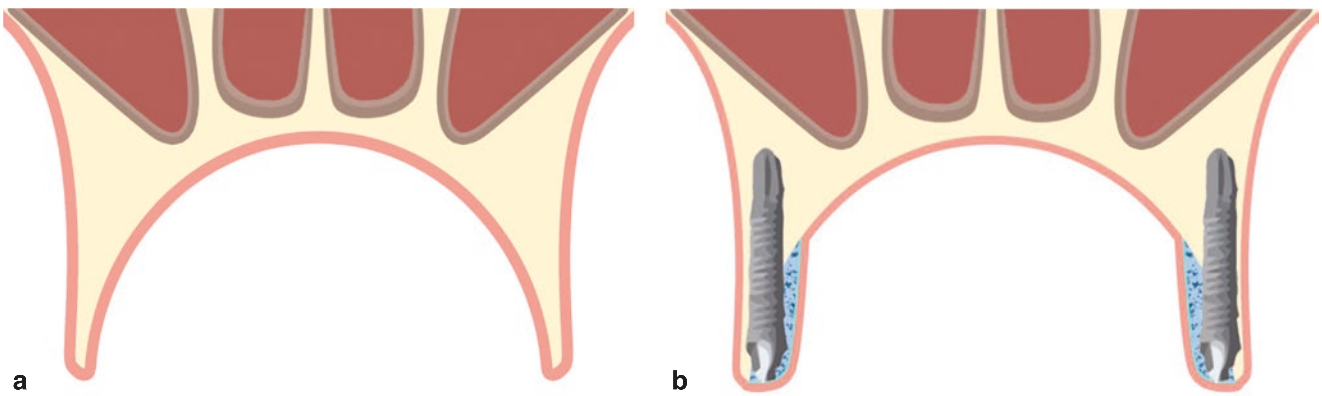

Fig. 11 Palatal implants. (**a**) Narrow bone crest. (**b**) Palatal implants with bone regeneration of palatal implant threads exposed. With this approach it is possible to maintain a thick cortical bone

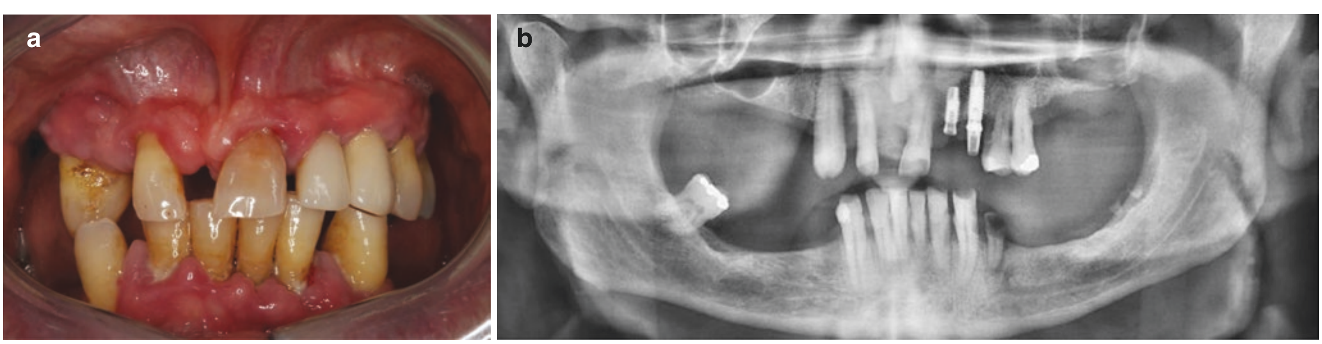

Fig. 12 (**a**) Initial intraoral and (**b**) panoramic X-ray of the patient. The patient demands to improve his function and esthetics. No bone presence in the posterior areas of both maxilla and mandible

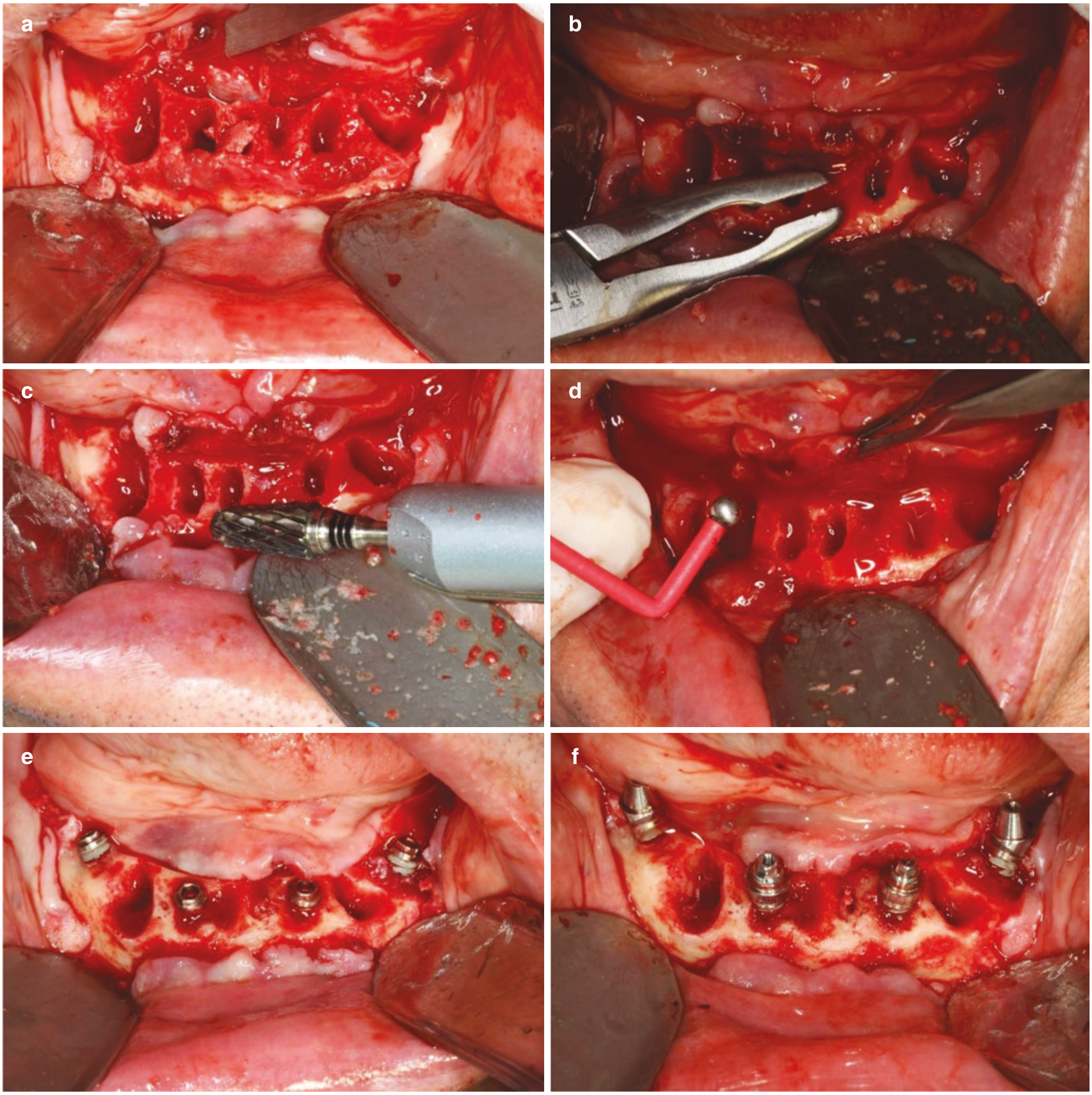

Fig. 13 Surgery of the mandible. (**a**) After teeth extraction a full-thickness flap was raised. (**b**) Beginning of the ostectomy with Gubia forceps. (**c**) Finish of the ostectomy with bur mounted in handpiece to create a more rounded and flat surface. (**d**) Control of bleeding with electrocautery. (**e**) Four implants were placed (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**f**) Prosthetic abutments positioned. (**g**) Preparation of A-PRF membranes (A-PRF™, Process for PRF, Nice, France). (**h**) Autogenous bone graft mixed with chopped A-PRF membranes. (**i**) Bone graft covering peri-implant dehiscences. (**j**) A-PRF membranes adapted to the implants covering the bone graft. (**k**) Flap suture

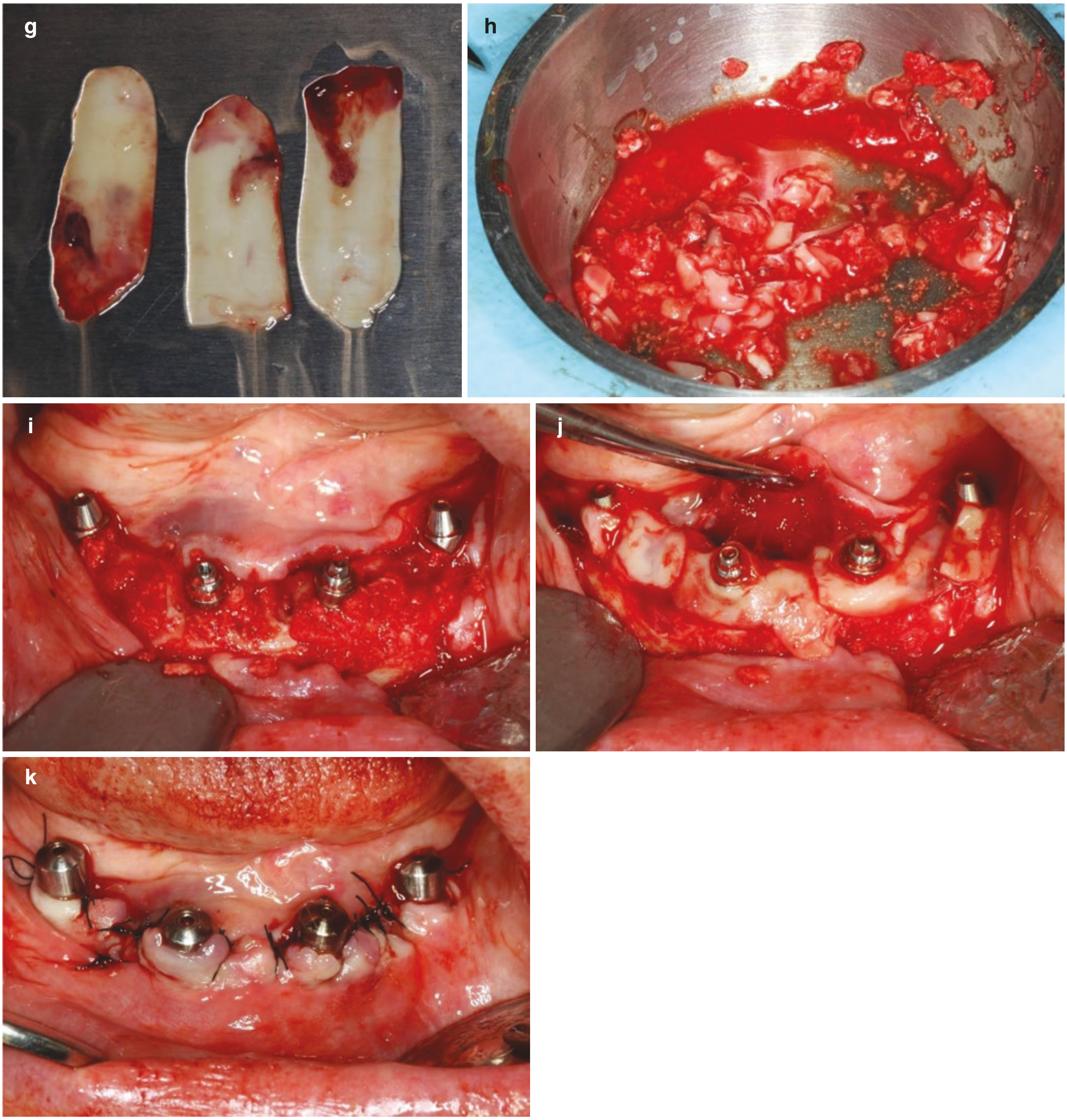

Fig. 13 (continued)

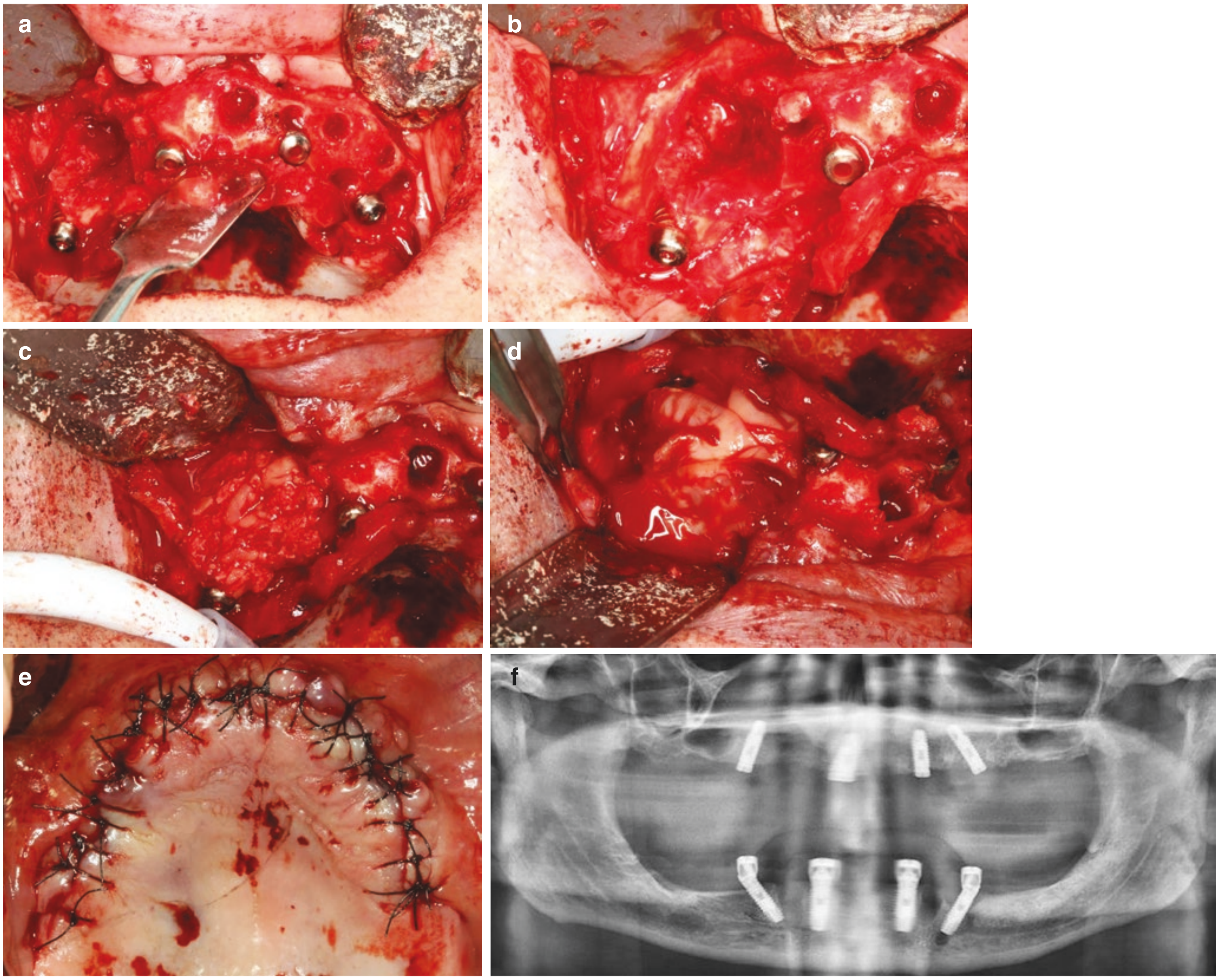

Fig. 14 Surgery of the upper maxilla. (**a**) Four implants were placed (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**b**) Big bone defect between the anterior and posterior implants of the upper right quadrant. (**c**) Bone defect filled with autogenous bone mixed with chopped A-PRF membranes. (**d**) A-PRF membranes covering the bone graft. (**e**) Flap suture. (**f**) Final panoramic X-ray after surgery

Fig. 15 (**a**) Temporary prosthetic rehabilitation of the mandible. Occlusal view. (**b**) Peri-implant soft tissue aspect at 1 week in the mandible and (**c**) in the maxilla at suture removal

Fig. 16 Definitive prosthetic rehabilitation. (**a**) Detail of the upper definitive prosthesis. (**b**) Detail of the lower definitive prosthesis. See the flat base of both restorations. (**c**) Intraoral and (**d**) extraoral aspect of the definitive rehabilitation. (**e**, **f**) Intraoral aspect of the peri-implant mucosa at 4 months. (**g**) Panoramic X-ray of the patient with the definitive restoration in place. See the excellent fit of the rehabilitation

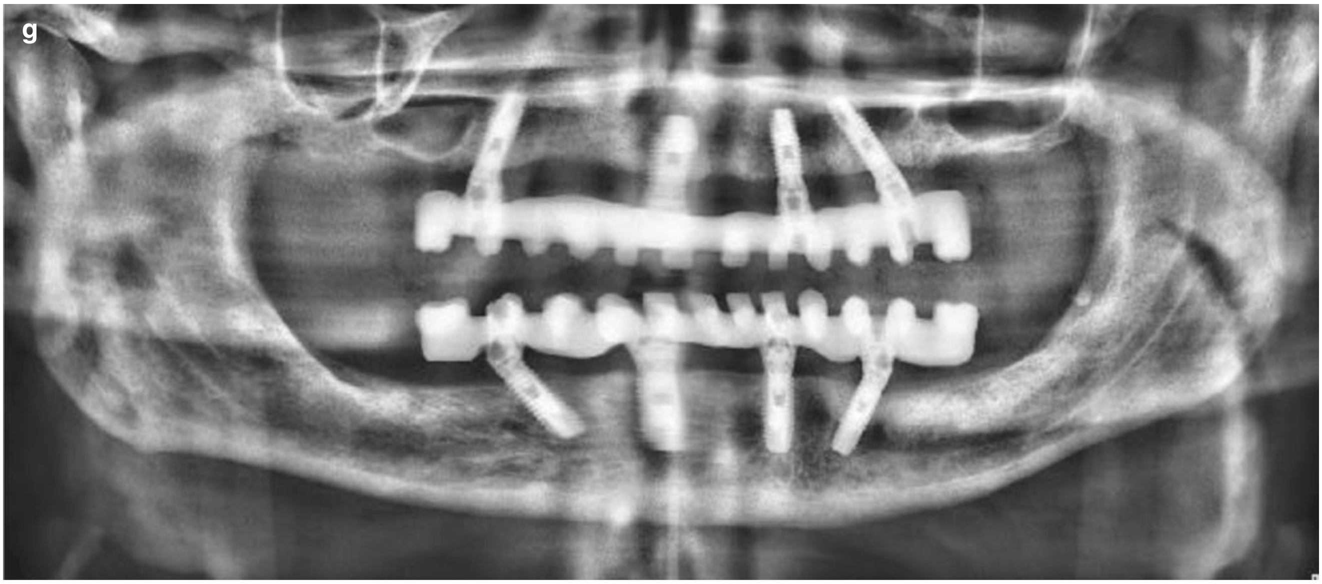

Fig. 16 (continued)

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Diagnosis and Planning in Immediate Loading: Prosthetic Diagnosis

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Abbreviations

CBCT Cone beam computed tomography
CT Computed tomography
PEEK Polyether-ether-ketone
VAS Visual analog scale

Take-Home Message

Immediate loading provides functional and esthetic advantages, improving the quality of life of the patient during the osseointegration period.

The three key parameters that should be evaluated for prosthetic planning of the totally edentulous patient are prosthetic space, lip support, and smile line.

The radiographic evaluation should include a prosthetic reference or guide that allows relating the alveolar process axis with the ideal prosthetic axis.

Introduction

Currently, the evolution in the treatment of implant surfaces as well as their design has made immediate loading a more frequently viable option, which does not differ significantly from conventional loading in terms of success rates. Like in any other medical or dental treatment, the correct diagnosis and planning of the case as well as careful surgical and prosthetic techniques are crucial to obtain favorable outcomes.

For this we must follow the general steps of a correct clinical history and specific diagnostic tests of implant-prosthetic treatment.

This case planning must be approached in an orderly and protocolized manner. This chapter proposes a schematization of the planning process in four phases that may or may not correspond with four clinic appointments depending on the means available in the clinic. The new digital might help reduce the number of clinical sessions to perform these four phases, but in no case this means that any of these phases can be ignored (Table 1).

Table 1 Diagnosis planning schema

Diagnosis protocol in implants prosthesis		
First phase	Second phase	Third phase
Clinical history: anamnesis and exploration	Assembly in the articulator	Radiological exploration: orthopantomography, lateral TeleRx, and CBCT
Photographs	Contact to laboratory: diagnosis wax-up and diagnostic-radiological splint	Prosthodontist-surgeon joint evaluation: location, inclination, size, and number of implants
Initial radiological analysis		Budget, informed consent, and sequence of appointments
Study models		

First Planning Phase

This phase includes clinical history data collection (anamnesis and clinical examination), photographs, initial radiological assessment, and obtaining study models.

The clinical examination includes the extra- and intraoral evaluation of the patient.

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Extraoral Examination

A systematic approach is recommended, examining the following parameters:

- Facial proportions: divided in three thirds; from hair edge to the eyebrows, from eyebrows to the subnasal point, and from the subnasal point to the chin (Fig. 1).
- Facial symmetry front and profile: parallelism of all these lines; bipupilar line, smile line, occlusal plane, and Camper plane.
- Need for lip and cheek support: patients with removable prostheses should be evaluated with and without the prosthesis (Figs. 2a–l, 3, 4, 5, 6, 7, and 8).
- Classification of the skeletal relationship: normal, prognathic, or retrognathic. See the relationship of the upper and lower lips to the esthetic plane (line from the tip of the nose to the chin).
- Intermaxillary relationship: vertical dimension (normal, increased, or reduced). In situations with a reduced vertical dimension, it is important to evaluate if it can be raised to the desired dimension with the consequent readaptation.
- Position of the edge of the maxillary central incisors and the occlusal plane: the position of the central incisors is evaluated at rest and in relation to the height of the smile line. The length of the lip is measured from the base of the subnasal column to the philtrum at rest, and it determines the visible height of the incisal edges of the upper central incisors at rest:
  – With a short upper lip length (10–15 mm), it has about 4 mm of visible incisor length.
  – With a medium upper lip length (21–25 mm), it has about 2 mm of visible incisor length.
  – With a long upper lip (31–35 mm), the incisors are barely visible.
- When the alveolar ridge is shown in patients with a high smile line, special consideration should be given to the esthetic aspects and the predictability of the result.
- Movement and function of the temporomandibular joint: hypertrophy or contraction of the facial muscles; it can be an indicator of parafunctional habits (along with facets of wear or attrition). The preoperative therapy of joint problems is indicated to reduce overload and offer a greater chance of successful treatment.

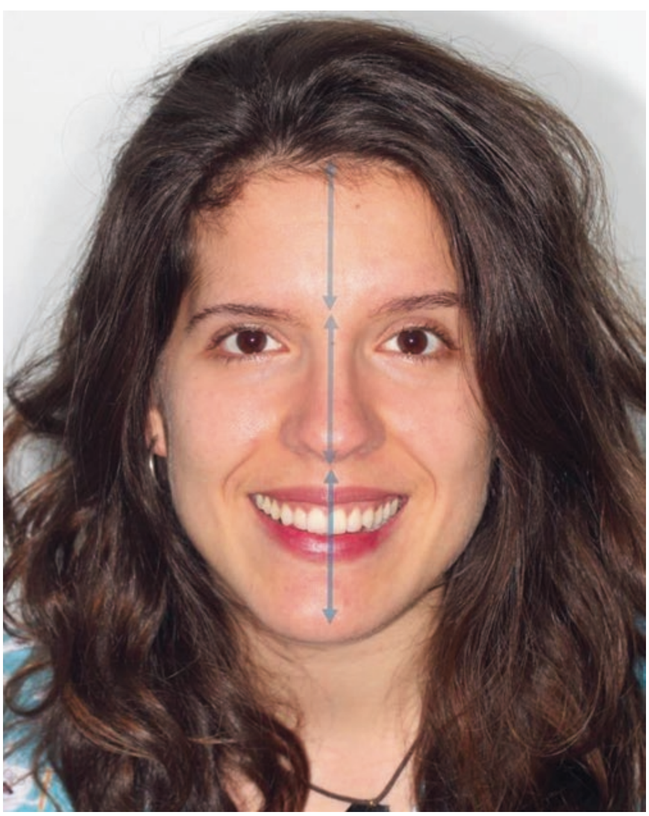

Fig. 1 Clinical image of the facial thirds

Intraoral Examination

The intraoral examination for prosthetic diagnosis includes the following aspects:

- Dental examination includes the existence of restorations, tooth decay, oral hygiene level, periodontal examination, pulp vitality test, malpositioned teeth (extrusions, intrusions, ectopic teeth), and deviation of the midline of the upper central incisors.
- Bone defects (vertical, horizontal, combined), crown-to-bone ratio (relationship between the ideal position of the clinical crown with the underlying bone), and possibility of compensation of the defect with hard or soft tissue graft or by prosthesis.
- Quality and quantity of the soft tissue and contour of the underlying bone tissue by probing and palpation. A suitable gingival thickness facilitates achieving the desired gingival contour.
- Existing prostheses: intermaxillary relationship; size, shape, position, and color of the teeth. If the previous aspects are correct, we can consider the same design for the new prosthesis based on it.

Initial Radiological Diagnosis

Panoramic radiographs provide adequate bidimensional vision, facilitate the detection of pathologies in the bone, and allow the evaluation of the amount of bone in the vertical and mesiodistal direction. They are a standard radiographic eval-

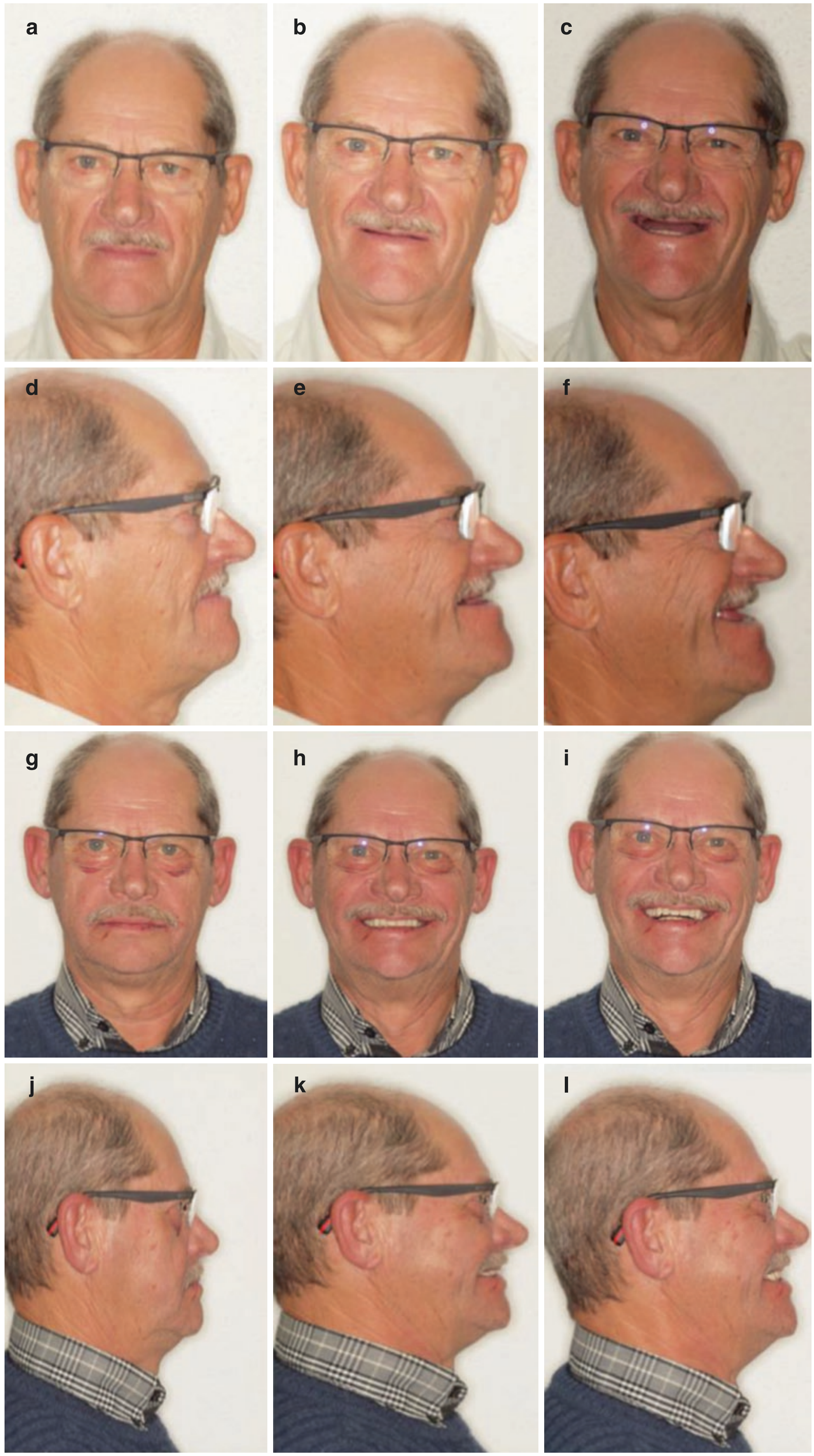

Fig. 2 Full-face extraoral photos to evaluate superior labial support without prosthesis and with immediate load prosthesis: (**a**) frontal photo at rest without prosthesis, (**b**) frontal photo in smile without prosthesis, (**c**) frontal photo in maximum smile without prosthesis, (**d**) lateral photo at rest without prosthesis, (**e**) lateral photo in smile without prosthesis, (**f**) lateral photo in maximum smile without prosthesis, (**g**) frontal photo at rest with prosthesis, (**h**) frontal photo in smile with prosthesis, (**i**) frontal photo in maximum smile with prosthesis, (**j**) lateral photo at rest with prosthesis, (**k**) lateral photo in smile with prosthesis, and (**l**) lateral photo in maximum smile with prosthesis

Fig. 3 Lateral view of the horizontal-vertical defect in labial support of the last third of the face

Fig. 4 Lateral view of the lack of labial support during the smile expression due to the detachment and resorption of the maxillary and mandibular alveolar process

uation method for the initial diagnosis and pre-planning of the treatment. In partially edentulous patients, it is recommended to perform periapical radiographs to facilitate a comprehensive treatment planning. Using a parallelization technique allows to evaluate the orientation of the roots of neighboring teeth.

Fig. 5 Front view of the defect in the labial support and decrease of the vertical dimension

Fig. 6 Lateral view of the restoration of the labial support and recovery of the vertical dimension after the placement of implant-supported maxillary and mandibular prostheses with replacement of dentoalveolar tissue

Today, performing a computerized tomography is mandatory to carry out an immediate load on implants. Computed tomography produces a third dimension, so it is different from the panoramic and periapical radiographs because it is an adjunct to the parasagittal plane and facilitates the evaluation of the amount of bone in the vestibulo-palatal direction. It offers a better orientation for the identification of anatomical structures and optimal placement of the implant (Fig. 9a–h). This type of radiology must be accompanied by a reference prosthetic component as a radiological splint that is the result of a previous diagnostic wax-up, and it will be done in the third phase of this planning protocol as will be seen later.

Fig. 7 Smile image after the end of the treatment

Fig. 8 Front view of the patient, where it checked the rehabilitation of the last third of the face

Planning using guided surgery software facilitates the production of surgical splints with perforations that allow a more accurate placement of the implant and the insertion of a prefabricated provisional restoration.

Photographs

The photographic record of the development of the treatment has become practically a necessity in the case of implants and must include at least the initial intraoral and extraoral situation of the patient, with the old prostheses and without them (if it is the case), the treatment concluded, and the details of the surgical, prosthetic, and laboratory phases that may be of interest.

This photographic archive will allow to document each case with images, to record the results of the different techniques used, and to review and analyze the treatments and their execution, and it is a way of communicating with our patients and with the rest of the companions. For this planning phase, both extraoral and intraoral photographs are detailed in the following tables:

Extraoral:

- Front facial (full face) at rest.
- Front facial smiling.
- Profile facial at rest.
- Profile facial smiling.
- Front (only mouth) at rest.
- Front smiling.
- 45° right and left smiling.

Intraoral:

- Front in occlusion with spacers.
- 45° right and left in occlusion with spacers.
- Front to the frontal sextant.
- Overall upper and down with mirrors.

Study Models

The initial clinical situation should be evaluated with the help of the study models. These can be obtained by analog procedures (silicones or alginates) or digitized by the use of intraoral scanners.

Second Planning Phase

It is one of the most important phases of planning since it will guide the clinician to the type of rehabilitation that is indicated for each patient. This second phase includes the assembly of the models in semi-adjustable articulator, analysis of the models, communication with the laboratory technician to make a tooth setup according to individual specifications, and, then, transforming it in a radiological splint.

Transfer and Analysis of Models

The transfer of the intraoral condition of the patient to dental models is a requirement in all presurgical planning. The models must be mounted on a semi-adjustable articulator with registers of centric relation and vertical dimension if it is lost or should be modified (Fig. 10a–c).

The planned changes in the position of the teeth or the correction of the midline are transferred to these models to inform the laboratory technician about the changes, which will be reflected in the diagnostic wax-up. This new configuration can be used for additional radiological analysis using a radiological splint, which will later be used as a surgical splint. Finally, this new configuration of the diagnostic wax-

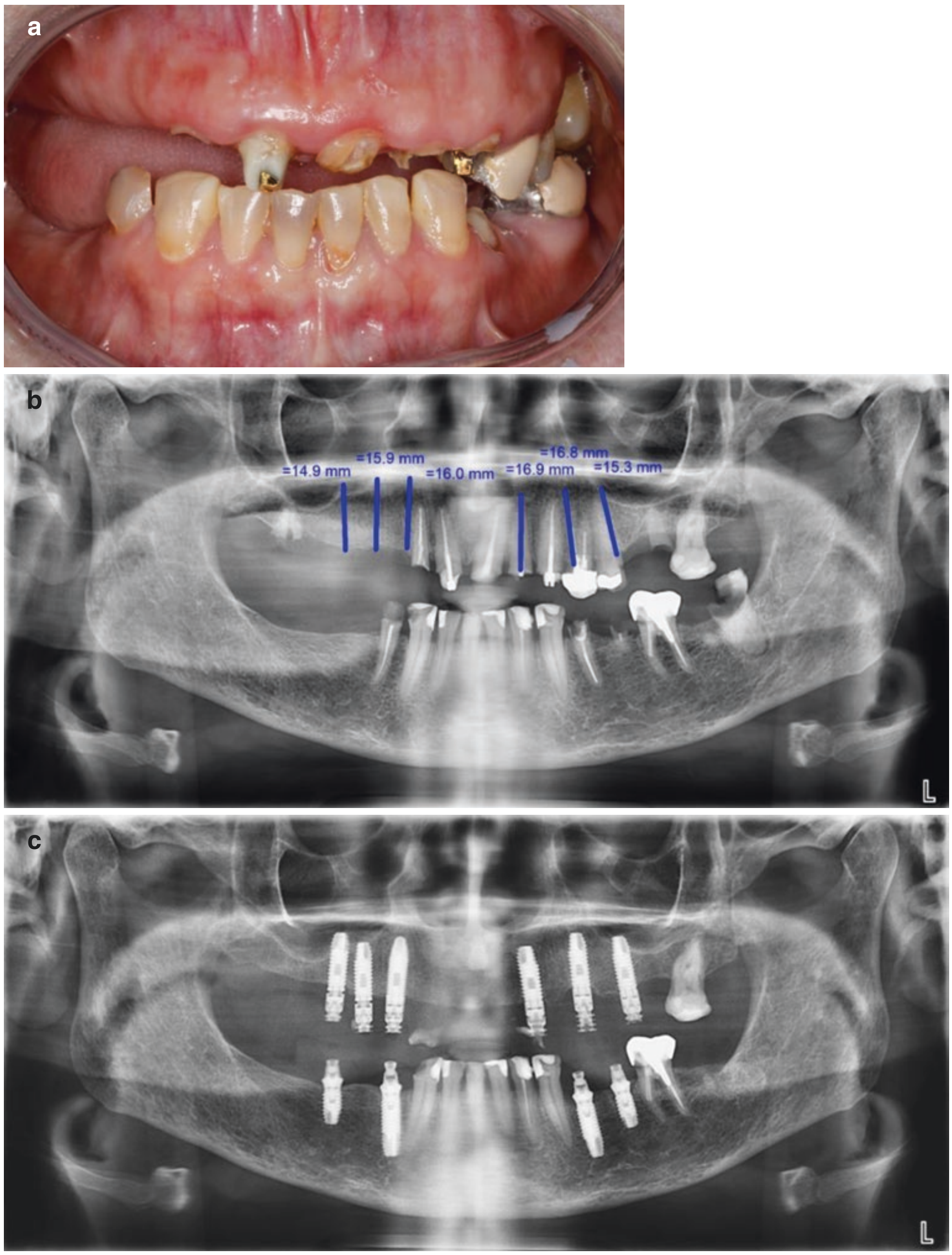

Fig. 9 Clinical case with planning using three-dimensional tomographic analysis (CBCT). (**a**) Intraoral initial clinic image on which it can carry out the planning of implant surgery. (**b**) Panoramic extraoral radiography with implant position planning. (**c**) Panoramic extraoral radiography with placed implant. (**d**) Axial section of maxilla when it can see the vestibule-palatine and mesiodistal position of the implants. (**e**) Section of the CBCT as a panoramic view. (**f**) Three-dimensional reconstruction of maxilla and jaw of the patient with the implant planning. (**g**) Coronal section of the CBCT which allows the evaluation of the vestibule-palatine position of two implants. (**h**) Intraoral final clinic image of immediate load provisional prosthesis

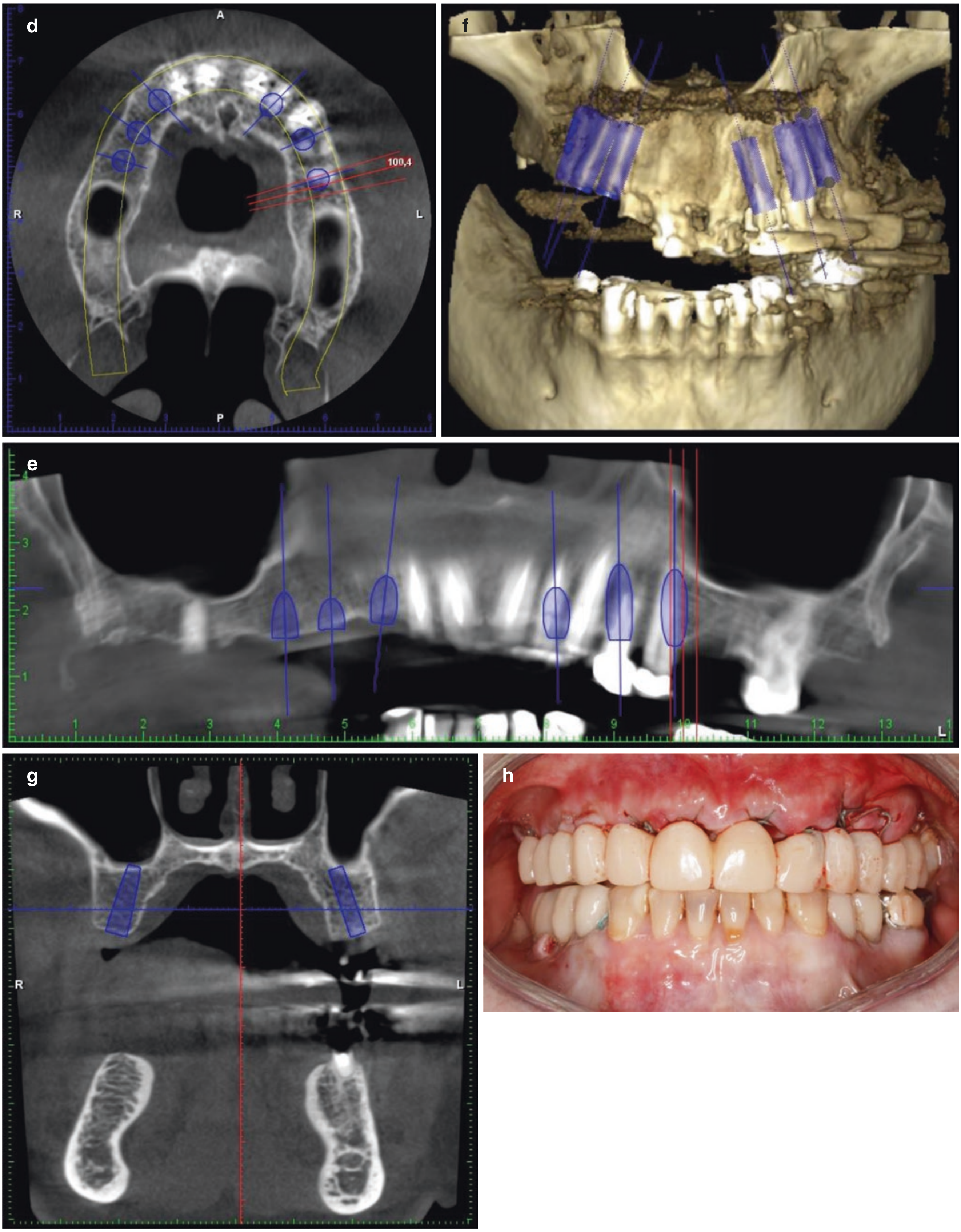

Fig. 9 (continued)

Fig. 10 (a) Cranio-maxillary transfer in the semi-adjustable articulator. (b) Assembly in the semi-adjustable articulator of bimaxillary implant-supported prostheses. (c) Front view of the assembly in the semi-adjustable articulator of the implant-supported bimaxillary prostheses in which it verifies the correct maxillary-mandibular relationship

up can be incorporated into the design of the provisional restoration.

It is key to know what is the relationship between the horizontal and vertical bone resorption with the ideal position of the teeth. When minimal resorption has occurred, the situation of the ideal clinical crown will normally coincide with the level of the soft tissues of the alveolar ridge. In situations of moderate to severe bone resorption, there is a large vertical distance between the ideal situation of the clinical crown and the underlying tissues that must be compensated by bone grafting techniques or by an increase in the artificial gingiva of the prosthesis.

Among the factors to be analyzed are the following: (1) occlusal centric relationship position, including premature occlusal contacts; (2) relationships of the alveolar crest with adjacent teeth and antagonist arches; (3) direction of forces in future implant sites; (4) occlusal diagram, including the presence of contacts on the sides of work and swing; (5) angulation, length, width, location, transmucosal esthetic position, muscular insertions, and soft tissue tuberosities without teeth; (6) space and relationship between both dental arches; (7) complete occlusal curves of Wilson and Spee; (8) antagonist dentition; (9) number of teeth lost; (10) location of future abutments in the archway; and (11) shape and asymmetry of the arch.

Diagnostic Wax-Up

Once the study models are assembled on the articulator, a diagnostic wax-up is performed, with the ideal position and morphology of the missing teeth and the reconstruction of alveolar process in case of atrophy (Fig. 11).

The diagnostic wax-up facilitates visualizing the characteristics, esthetic conditions, and relations with the different oral structures. The analysis of the models contributes also to obtain valuable information for implant treatment planning: number, location, and direction of the necessary implants. In partially edentulous patients, it will consist of a wax-up of the missing teeth, and for totally edentulous ones, it will request a tooth setup in wax-up.

The three fundamental parameters that it has to evaluate in the tooth test of the totally edentulous are:

1. Prosthetic space.
2. Lip support.
3. Smile line.

1. Prosthetic space: it determines the type of prosthetic restoration.
2. Lip support: to be able to perform a correct preview and diagnosis of the total edentulous patient, a wax-up with vestibular flange can be requested. The flange can be eliminated during the tooth setup assessment, and thus the patient's profile and the smile line with and without the vestibular flange can be assessed. This will give very valuable information about what type of prosthesis is suitable for the patient (Fig. 12).
3. Smile line: in addition to the evaluation of the labial support, another determining parameter in the upper totally edentulous patient is the smile line. Special care must be taken when the patient shows the transition interface between prosthetic gingiva and alveolar process when smiling, since this will condition the design of the future prosthesis and even surgical planning with crestal osteotomy techniques (Fig. 13).

Fig. 11 Pretreatment diagnostic wax-up

Therefore, the diagnostic wax-up will allow us to preview the ideal rehabilitation, the real prosthetic space, the esthetics, and the need to replace the gingiva as well as the implant-prosthetic tooth position (Sadowsky et al. 2015).

The wax-up must be placed in patient's mouth, and esthetics, phonetics, and functions must be checked so leading to a high level of acceptance (Chiapasco 2004; Misch et al. 2004). After confirming that the patient is satisfied with the form, color, and shape of the interim wax-up, provisional prosthesis fabrication can be finalized.

Diagnostic-Radiological Splint

Once the diagnostic wax-up or tooth setup has been tried and corrected, this will be transformed into a radiological splint to be worn by the patient when performing a CBCT. It is crucial to have a reference prosthetic component in the

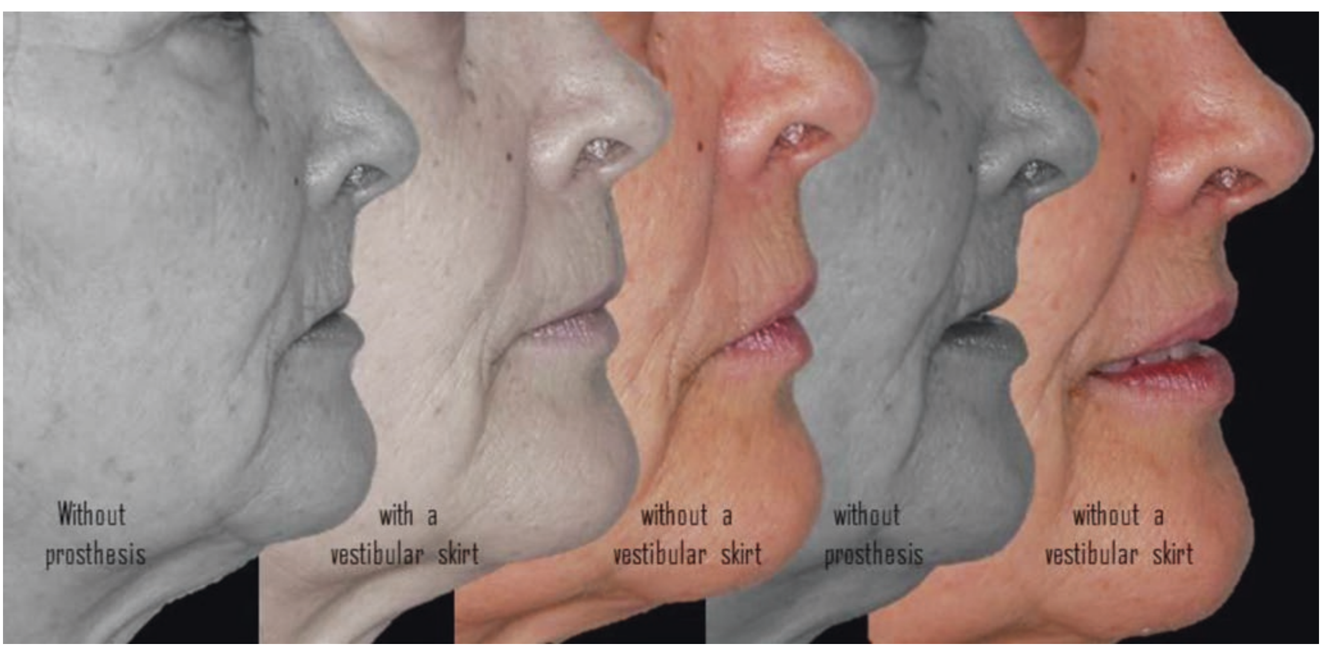

Fig. 12 Diagnostic wax-up with and without vestibular skirt: effects in upper labial support

radiological examination that allows to relate the bone axis with the ideal prosthetic axis.

For its preparation, a duplicate of the dental part of the wax-up in radiopaque material and the bases in transparent radiolucent material will be made. In case of guided surgery, the radiological splint must fulfill the criteria specified by the protocol of each system.

Third Planning Phase: Three-Dimensional Radiology

In this phase of the diagnosis, the specific radiographic exploration by means of three-dimensional radiology is done.

Fig. 13 Image of excessive exposure of the prosthetic vestibular skirt during the patient's smile

The visualization of the prosthetic tooth during the bone availability study allows to plan the three-dimensional position of the implants according to the planned prosthetic rehabilitation. This will minimize unwanted angulations of the implants that imply an increase in technical complexity as well as esthetic problems in the prosthodontic phase.

Knowing the foreseeable position of the implants allows to make a selection of abutments from early phases, especially interesting in cases of correction of angulations conditioned by bone availability. All this information will help to have a better planned prosthetic phase and therefore with fewer complications (Fig. 14a, b).

Currently, there are numerous radiology software that help in this planning task. These software incorporate implant libraries with the morphology and real size of the different commercial brands. These software will allow the virtual placement of the implants in an ideal position according to the prosthetic tooth and the assessment of bone availability in the area avoiding complications at the time of surgery, for example, fenestrations, invasions of anatomical structures, etc.

Fourth Planning Phase: Decision-Making

After collection of information during the first three phases, the planning finishes with the decision of type of prosthesis and number and position of implants and prosthetic abutments. This will allow to prepare a personalized budget as well as a treatment plan with the temporal sequence and informed consent for the patient.

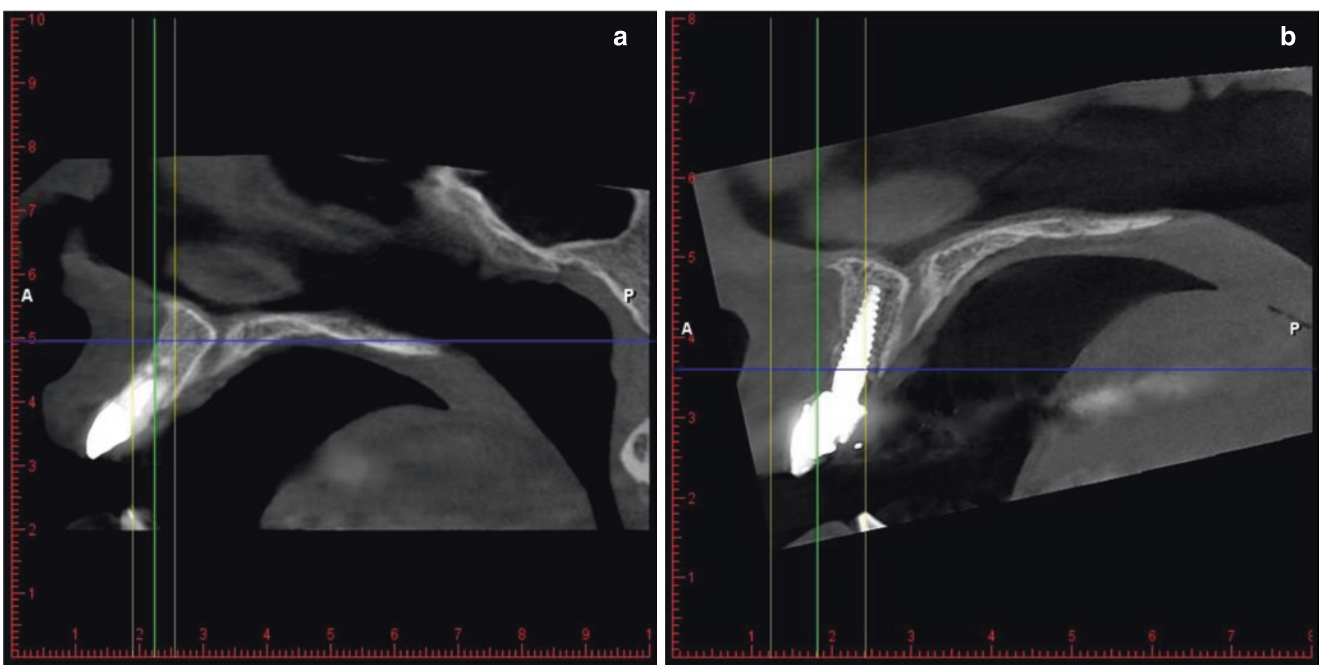

Fig. 14 (**a**) Pretreatment tomographic section of the alveolar bone and the remaining tooth. (**b**) Posttreatment tomographic section in which the correct relation of the bone and the implant is appreciated after 6 months of prosthetic load

Type of Prosthesis

In the following tables, the characteristics of the different types of prostheses on implants according to several parameters are summarized (Tables 2 and 3). The advantages and disadvantages of cemented and screwed prostheses are also shown (Table 4).

Prosthetic Abutments Used in the Immediate Loading

The immediate load prosthesis will be made on provisional abutments as:

- Titanium abutments: very resistant abutments indicated for the preparation of provisional hybrid prosthesis.
- Plastics abutments of plastic material (methacrylate): they are very weak abutments, only indicated for prosthetic loads of reduced time.
- PEEK resin abutments: these abutments are made of a material (polyether-ether-ketone) which is a high-strength resin. They carry a mechanized connection so that the implant connection is not subjected to a porous material and it is deformed.

These transmucosal abutments are connected to the implant by surfaces that can have the following characteristics:

Table 2 Characteristics of implant prosthesis in maxilla

Maxilla	Fixed rehabilitation	Hybrid prosthesis	Overdenture	Rehabilitation fixed-removable
Replacement	Clinical crown	Clinical crown and alveolar process	Clinical crown and alveolar process	Clinical crown and alveolar process
Degree of resorption	Scarce or null	High	Very high	High-moderate
No. of implants	6–8 Well distributed	4–6 Cantilever	4 (+2 + 4)	4–8 Badly distributed Poorly oriented
Connection	Cemented Screwed	Screwed	Bar Balls Magnetos	Screwed (infrastructure) Friction (suprastructure)

Table 3 Characteristics of implant prosthesis in jaw

Jaw	Fixed rehabilitation	Hybrid prosthesis	Overdenture	Rehabilitation fixed-removable
Replacement	Clinical crown	Clinical crown and alveolar process	Clinical crown and alveolar process	Clinical crown and alveolar process
Degree of resorption	Mild	High	Moderate	High-moderate
No. of implants	6–8 Well distributed	4–6 Cantilever	2	4–8 Badly distributed Poorly oriented
Connection	Cemented Screwed	Screwed	Bar Balls Magnetos	Screwed (infrastructure) Friction (suprastructure)

Table 4 Comparative cemented and screwed prosthesis

Cemented prosthesis		Screwed prosthesis	
Advantages	Disadvantages	Advantages	Disadvantages
Esthetic occlusal surface	Difficulty removal	Simplicity in its removal	Occlusal esthetics
Ease of passive adjustment	Little adaptation precision	High precision in single crowns	Difficulty obtaining passive adjustment
Simple manufacturing	Need for provisionalization using cement		Complex manufacturing
Fullness of the occlusal surface	Difficulty in removing excess subgingival cement		Bacterial colonization through the access forums to the closure screws
			Possible complications at the level of the closing screws
Lowest cost			High economic cost of the components

- Anti-rotation: based on reciprocal geometric figures in its most apical part, to avoid rotation of the abutment on the implant.
- Rotational: formed by a circular connection.

As recommendations for choosing different abutments for the fabrication of provisional prosthesis on implants, in the study published by Agustín-Panadero et al. (2015), in which the resistance to in vitro mechanical loading of five groups was analyzed ($n = 10$) of transepithelial abutments on hexagonal internal connection implants (UCLA methacrylate abutment with titanium anti-rotational machined base, PEEK resin abutment with titanium anti-rotational machined base, titanium provisional abutment with anti-rotational connection, titanium definitive abutment with rotational connection, and titanium final abutment with anti-rotation connection). The obtained load values were the following: Group titanium anti-rotational definitive abutments achieved the greatest compression strength, with a mean fracture resistance of 1106.7 ± 344.4 N. The group presenting the lowest resistance was group PEEK resin provisional abutments, with a mean fracture resistance of 329.4 ± 103.6 N. Group titanium provisional posts showed the second highest values, with a mean fracture value of 985.4 ± 350.3 N. Group titanium definitive abutments with rotational connection was in third place with a mean fracture value of 853.3 ± 409 N. In penultimate place, group methacrylate provisional abutments with machined titanium base presented a mean of 370.7 ± 137.8 N.

So, based on the literature, a recommendation can be done on the use of the different transepithelial abutments:

- Use the abutments of methacrylate in situations of less than 3 months in the mouth and the need for immediate esthetics without load.
- The PEEK resin abutments are also used in situations of less than 3 months in the mouth and the need for immediate esthetics under load.
- In situations in which the provisional has to stay functional for 3 to 6 months in the mouth, the provisional titanium abutments will be used, which have greater strength, and the behavior is similar to the definitive titanium abutments. It is recommended for multiple temporary prostheses.
- The definitive titanium abutments allow it to use provisionals, when this phase lasts between 6 months and 1 year. These abutments will also be used with the final prosthetic treatment once the provisionalization phase has passed.

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Diagnosis and Planning in Immediate Loading: Surgical Diagnosis

Ugo Covani, Enrica Giammarinaro, Paolo Toti, David Soto-Peñaloza, Giovanni B. Menchini Fabris, and Simone Marconcini

Abbreviations

3D	Three-dimensional
CBCT	Cone beam computed tomography
CT	Computed tomography
DICOM	Digital imaging and communications in medicine
HU	Hounsfield units
IT	Insertion torque
Ncm	Newtons per centimeter
PT	Periotest
RFA	Resonance frequency analysis

Take-Home Message
Accurate surgical diagnosis is a matter of both clinical and radiological evaluations. Three-dimensional imaging has changed modern implantology making it safer and more repeatable. Despite technological innovations, the surgeon pursuing immediate loading should be experienced and should have gone through a deep understanding of the patient's needs, expectations, and surgical indications to treatment.

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Introduction

A careful evaluation of the alveolar ridge morphology is a prerequisite to implant treatment procedures. Clinical measures such as palpation, calipers, and cast models analysis have several limitations. Radiographs are of utmost importance to implant dentistry. For several decades, two-dimensional images were the only available for the surgical diagnosis prior to implant placement. The introduction of digital radiology and software applications for three-dimensional imaging has increased the prospects of success in implant diagnosis and surgical placement (Fig. 1).

Dental cone beam computed tomography (CBCT) allows volumetric analysis and surgical planning with reasonable radiation doses and costs. Clinicians can visually plan the best position and inclination for implant placement with a high degree of accuracy. Furthermore, data obtained by CBCT and implemented on three-dimensional (3D) software could be gathered together with clinical pictures and virtual

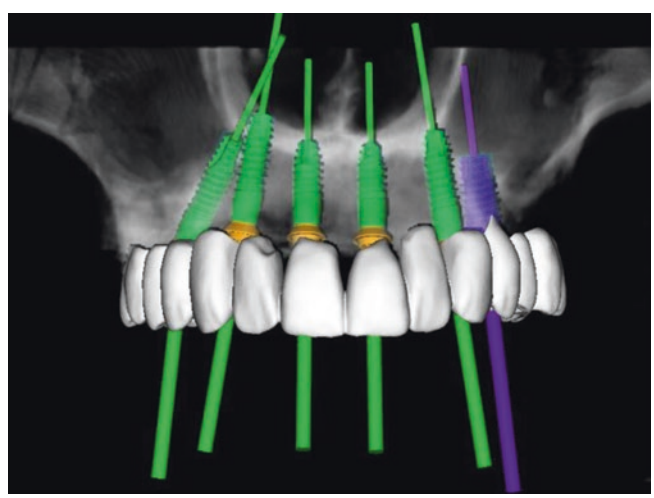
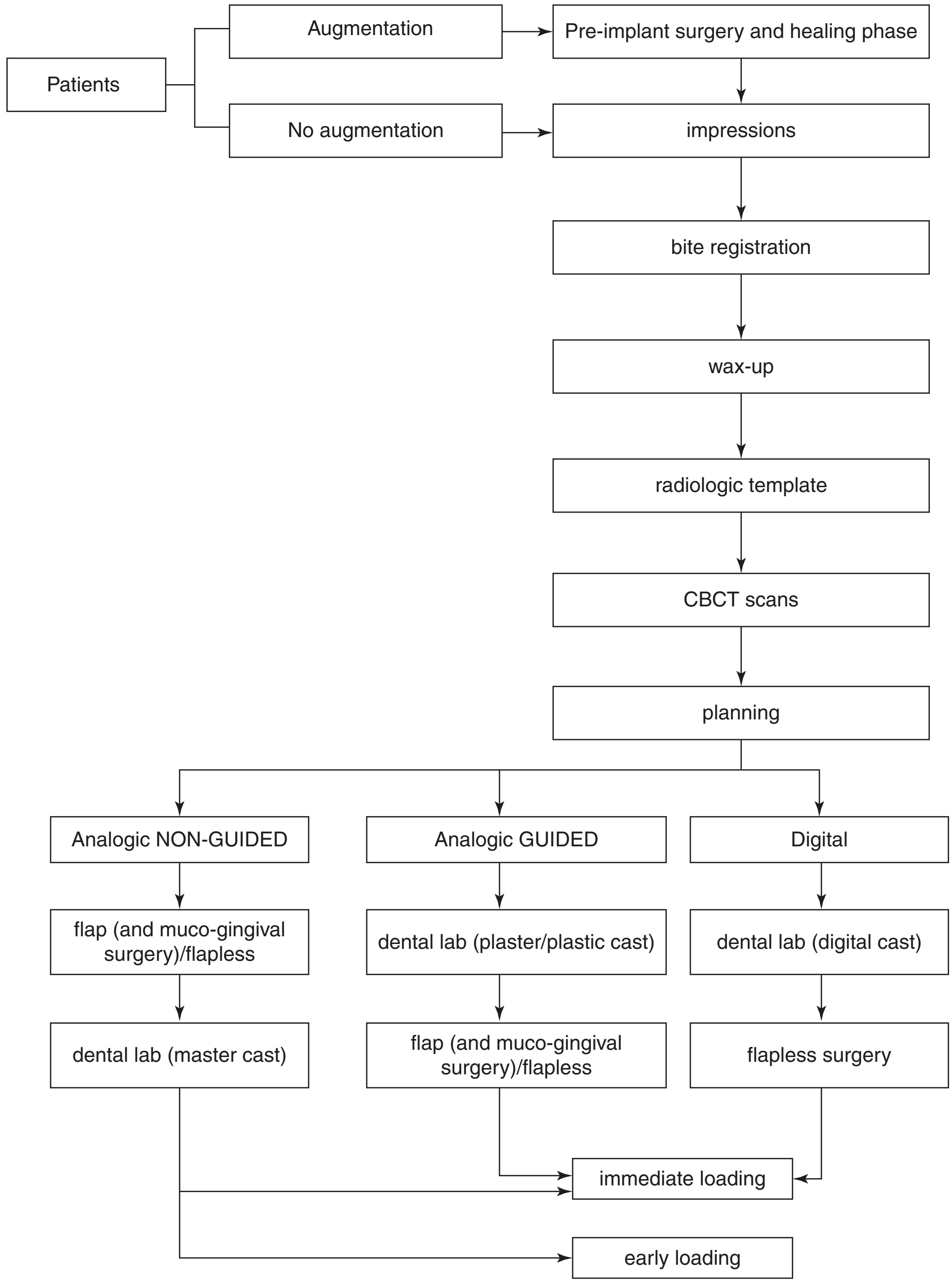


Fig. 1 Virtual representation of the maxillary process and implant planning according to prosthetic and surgical indications

M. Peñarrocha-Diago et al. (eds.), *Atlas of Immediate Dental Implant Loading*, https://doi.org/10.1007/978-3-030-05546-2_8

Fig. 2 Possible treatment workflows for implant planning in immediate loading with three-dimensional scans



treatment schemes in order to create a complete patient profile speeding up the entire implant workflow.

Guided surgery was one of the main features coming with the introduction of 3D imaging and software. In the hands of an expert surgeon, guided flapless surgery shortens the healing period, increases patients comfort, and prevents unaesthetic scars or mucogingival-level alterations, overall minimizing bone changes (Chen et al. 2009). Figure 2 summarizes the possible treatment workflows for implant planning in immediate loading with three-dimensional scans.

Radiographic Analysis

The radiological evaluation is vital to the clinician who is about to perform implant surgery. The recommended approach toward radiology is dual: it is useful to visualize anatomic landmarks in order to preserve noble structures, but the clinician should also exploit the maximum from digital imaging in terms of site-per-site implant planning (Fig. 3). Despite individual variation, the study of 3D imaging provides repeatable anatomical landmarks at each tooth site which are useful at the moment of deciding implant angula-

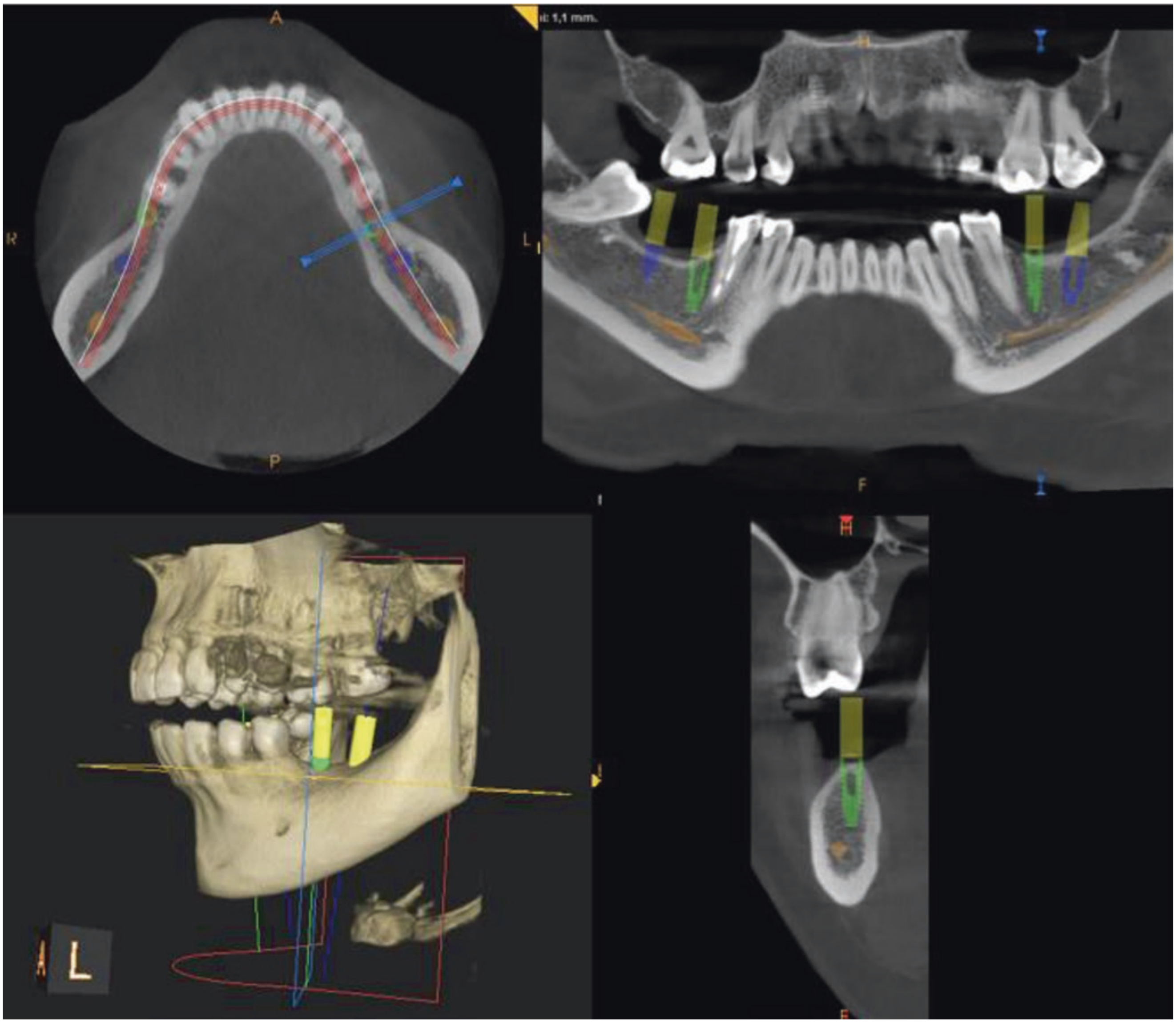


Fig. 3 3D imaging allows a site-per-site approach toward implant planning

tion. The consecutive study of several 3D scans guarantees the acquisition of anatomy-oriented implant planning.

Two-Dimensional Diagnostic Radiographic Examination

The immediate loading protocol certainly requires a diligent examination of the jaw size, inter-arch relationship, maxillo-mandibular distance, occlusal relation, and bone status. When the residual crest appears tortuous and sharp, with unstable narrowness, the actual width of the alveolar ridge can be clinically determined by few mucosal punches in the implant recipient area.

The CBCT is definitely more precise and complete than panoramic radiography, but it is not always mandatory for every case. For example, panoramic radiographs are sufficient for preimplant evaluation for routine cases in which implants of suitable length can be inserted safely (Luangchana et al. 2015). Luangchana and colleagues suggested that when the available bone is 0–2 mm longer than the selected implant length, preoperative CBCT examination is recommended to determine the bone height more accurately and to identify fine anatomic structures. In cases in which the available bone is more than 2 mm longer than the selected implant length and the width of the alveolar bone is adequate, panoramic radiographs are sufficient to measure bone height.

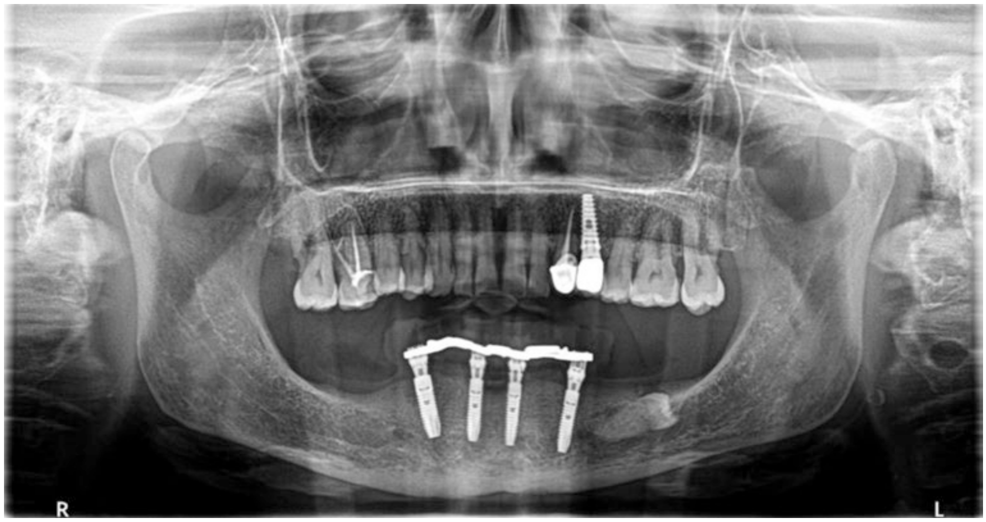


Fig. 4 Panoramic radiograph for surgical diagnosis for a flapped all-on prosthesis in the lower mandible. The intra-foramina jaw bone is often sufficient to receive 4–5 implants for immediate loading purposes. The panoramic radiograph might be sufficient when there is a fair amount of bone volume in this area and when the surgeon is going to raise a full-thickness flap in order to have more field of vision

In the mandible, even in severely atrophic ones, the intra-foraminal zone usually maintains enough bone volume for successful fixed prosthetic rehabilitation. When considering the area between the mental foramina, in everyday cases, a panoramic radiograph may be sufficient to detect anatomic structures and to guarantee the presence of adequate bone height for the placement of implants from 10 to 15 mm in length (Fig. 4). It is fundamental, especially for the novice to focus on the drill: it should be the surgeon guiding the drill and not the opposite. In fact, without guidance, the drill would follow the bone *loci* of least resistance, probably missing the intended implant position.

After the reflection of a full-thickness flap, the surgeon prepares the implant bed by means of increasing diameter drills. At this stage, the clinician can change the length, diameter, inclination, and position of the fixture to adapt surgical procedure to concomitant alveolar ridge contour, checking the thickness of the available bone with a surgical caliper.

The fixture direction can be clinically controlled by surgical pins, whereas relative position among several implants can be checked by paralleling gauges (Fig. 5).

After the confirmation of the correct direction of the implant site preparation, the clinician completes the final drilling and places the dental implant. Even if the resistance to implant insertion can be subjectively evaluated, the clinician can simply and objectively record implant insertion torque (IT) by manual or digital torque gauge (Barone et al. 2016).

IT value allows the surgeon to know whether the implant has to be loaded immediately, early, or with delayed prosthetic treatment: only implants showing an IT > 30 Ncm should be immediately loaded.

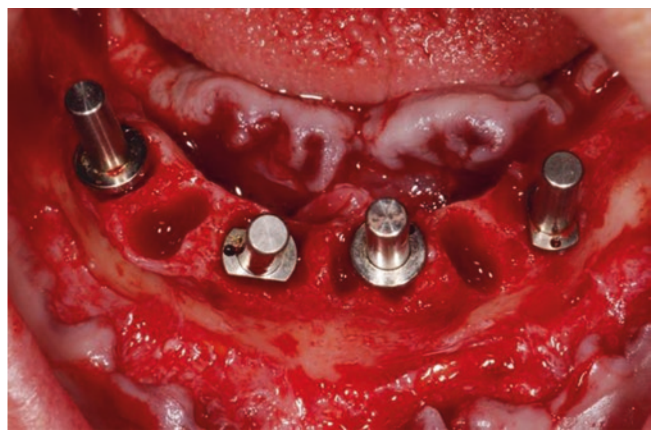


Fig. 5 Paralleling pins could be used to check the direction and parallelism of the implant sites. At this moment, the surgeon has the possibility to slightly change the direction of one or more implant beds to correct dis-parallelism or wrong angulation

Three-Dimensional Diagnostic Radiographic Examination

Success for fixed implant-supported rehabilitations, especially in immediate provisionalization techniques, depends on accurate pre-surgical evaluation of the following issues:

1. Recognize feasible restoration procedures to rehabilitate patient edentulism.
2. List all the therapeutic possibilities, even if non-fixed solutions, evaluating the cost/benefit ratio of all treatments.
3. Suggest the most correct treatment to the patient, after accurate evaluation of patient's chief complaints.

4. Diagnosis and treatment proposal should be verified with a team that can supply technical support through knowledge and expertise about surgical, prosthetic, and laboratory requirements.

With the aid of computed tomography (CT) scans, it is possible to verify the presence of adequate bone volume and absence of pathologies that might prohibit/interfere with implant installation. Table 1 summarizes all of the clinical informations provided by CBCT (Jacobs and Quirynen 2014). If adjunctive problems are encountered, i.e., related to the maxillary sinus, the patient should be evaluated by an ENT surgeon and, if necessary, treated. In case of partially edentulous patients, infected teeth covered by metal or metal-ceramic crowns must be extracted before scans due to distortion caused in the postproduction of the matrix file, whereas other metallic prostheses can be retained if the patient is correctly oriented in space (referring plane is adjusted parallel to the occlusal surface of the metallic prosthesis) with maxillary arcs well separated by an inter-occlusal support.

The patient is guided into centric occlusion, and 3D computer tomographic scans (via CT or cone beam CT [CBCT]) are acquired, and data are recorded using the digital imaging and communications in medicine (DICOM) protocol. Several Dentascans can allow assessment of the jawbone volume in the three dimensions and of the bone density expressed in Hounsfield units (HU).

The optimal position of dental implants can be planned by using cross-sectional images: the clinician can manually superimpose transparent implant templates on image films or virtually place dental implant phantoms into the 3D scene by means of dedicate software (Anatomage, Materialise, NobelGuide). Three-dimensional analysis of the alveolar ridge helps in the diagnosis and safe treatment planning of immediate loading. In the case of a non-guided surgery, 3D scans help in the visualization of anatomical structures and bone quality in the prospective implant areas. However, the surgeon will not have a direct way to correlate computer images to the mouth, unless CT scans are acquired making the patient wear a radiographic template.

CBCT has been tested for measurement agreement among different observers by Lofthag-Hansen et al. (2009): the authors found a high confidence among the observers evaluating the marginal bone crest and the mandibular canal, therefore recommending CBCT for implant planning in the mandible.

The clinical execution remains strictly related to the skill and manual dexterity of the surgeon, who needs to incise the crestal mucosa, to raise a muco-periosteal flap, to favor good sealing of the peri-implant soft tissues, and to manually position dental implants with no physical support for the drill.

Table 1 Clinical informations provided by cross-sectional imaging low-dose cone beam computed tomography

Treatment phase	Clinical information
Pre-implant diagnostics	Prognosis neighboring or doubtful teeth
	Remodeling extraction site(s)
	Presence of bone lesions, sinus, and/or tooth pathology
Preoperative planning of implant placement	Determination of anatomic boundaries
	Reliable visualization of jaw bone neurovascularization
	Information on bone volume and planning grafting
	Information on bone morphology
	Information on bone quality and trabecular structure
Transfer to surgery	Integration of anatomic, functional, biomechanic, and esthetic factors
	Decision for computer-assisted surgical transfer
Peri-implant follow up	Diagnosis of postoperative complications
	Follow-up of managing complications

Three-Dimensional Flapped Analogue-Guided Surgery

Besides the three-dimensional image explorations, an analogue surgical guide can correlate the preoperative plan with the intraoperative site. Analogue term means “manually fabricated” by the dental technician with no direct mathematical or digital link between the CT images and the drilling machine; the dental technician drills and positions the implants’ guide tubes within the surgical template on the basis of the information comprised into plaster cast or prototyping models of the jaw following implant positions, directions, lengths, and diameters desired by the clinician.

Surgical guides are classified to the type of supporting anatomic structure such as tooth, bone, or mucosa (see next sections). In partially edentulous patients, the template can be stabilized on the remaining teeth, and it is proven that the smallest deviations appear between planned and practiced surgery (Ozan et al. 2009), whereas, if the jaw is edentulous, different authors suggest to prefer mucosa- to bone-supported guides (Arisan et al. 2010). The most common techniques to stabilize surgical guides are rigid screws or fixation pins, the latter either drilled or stuck in the cortical bone. Moreover, with bone-supported guide, the clinician has a higher direct control during the dental implants’ placement than with a flapless procedure (Fig. 6a–d).

The following main scheme could be applied for flapped analogue-guided surgery:

1. Based on an alginate impression of the patient’s jaw, a radiological template is fabricated.
2. CT scans of the patient wearing the template in place stabilized in a centric occlusion by bite registration paste are acquired.

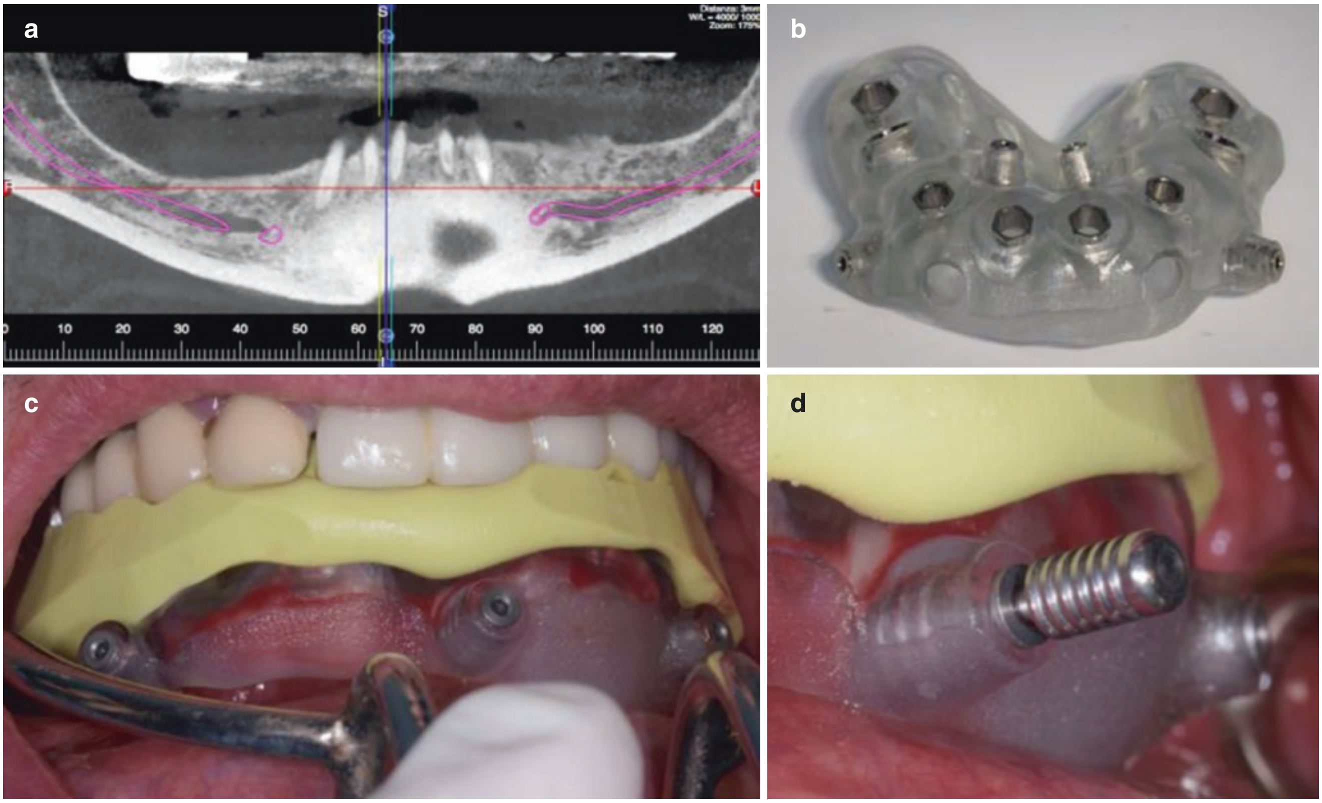


Fig. 6 An example of surgical guide for the inferior jaw fixed to the bone. (**a**) Mental nerve path in CBCT imaging. (**b**) Acrylic surgical template guide, for mandibular arch. (**c**) Surgical template positioning with customized silicone. (**d**) Fixation pin inserted and surgical guide placed in final position

3. The Dentascan software loads the acquired data in DICOM format.
4. A master cast is duplicated, or a prototyping model is fabricated from three-dimensional images (bone-level threshold: HU > 350–500).
5. Analogues of implants are now manually placed into jaw surrogate such as plaster cast (in case of tooth-supported guide) or as bone prototyping model (in case of bone-supported guide). Abutments can be contemporarily connected to the implant replicas in order to fabricate a wax-up of the implant-supported fixed superstructure prior to surgery (alternate hypothesis is that impression can be made after implant placement and provisional restoration fabricated within the first day after surgery).
6. The dental technician transforms the master drilling plan into a surgical template.
7. A cross-check of the placement of the guidance tubes, to ensure they reflect the planned placement, is performed; if necessary, the planned position can be changed and the template redrilled. At this point the provisional restoration could be fabricated.
8. The template is placed into the mouth, and the dental surgeon drills the pilot boreholes by simply placing the drill into the tubes of the template up to the mark on the drill (Fig. 7).

Fig. 7 The holes on the surgical template guide implant bed preparation

Three-Dimensional Flapless Analogue-Guided Surgery

Flapless guided surgery with mucosa-supported surgical templates has reduced the length and invasiveness of implant treatment. Table 2 reports the main requirements to

Table 2 Indications to flapless surgery

Requirements to flapless surgery	
Mucogingival morphology	Scarce soft tissue representation
Mucogingival junction (MGJ)	Distance between MGJ and bone crest ≧ 2 mm
Bone	A good amount of bone volume
Surgical hint	Keep the alveolar process between the fingers while drilling

flapless surgery. A flapless surgery requires accurate investigation regarding wideness and thickness of the keratinized soft tissue covering the underlying bone structures. The soft tissue thickness can be clinically measured by probing, under local anesthesia, or by CT scans, while the patient is wearing a radiological template in centric occlusion; the empty space between template and bone represents the mucosa.

Surgical guides in partially edentulous patients are tooth-supported; but if the patient's jaw is totally edentulous, mucosa-supported surgical guide can be helpful.

The pillar concepts for mucosa-supported surgical guides are:

1. Limited attached keratinized gingiva around implant site insertion. The healing of peri-implant tissue is negatively affected by flap raising and results in soft tissue shrinkage. If no soft tissue augmentation procedure is required, a flapless approach via mucosa-supported surgical guide is the right choice.
2. Small amount of bone. It is proven that flap procedure leads to a negative bone remodeling, higher than that registered in a flapless surgery. In sites in which the bone volume of alveolar ridge is just enough to place dental implant, a flap raising could jeopardize the success of the long-term outcome.

The placement in loco of a mucosa-supported surgical guide is a very difficult act, consisting, at start, of a perfect surface fitting between the mucosa and the lower border of the guide, followed by manual pressure and by rigid fixation of the guide to the underlying bone by means of guided anchor pins or screw (Van Steenberghe et al. 2005).

The following scheme could be applied for flapless analogue-guided surgery:

1. Fabrication of radiologic template by using master casts
2. Acquisition of patient CT scans with template in centric occlusion
3. CT scans loading and virtual placement of dental implants in the bone volume identifying correct position and orientation by using 3D planning software environment
4. Duplication of master cast or fabrication of prototyping model (stereolithographic jaw surrogate with bone-level threshold: HU > 350–500)
5. Transfer of digital settings onto the physical models (plaster or plastic cast)
6. Fabrication of surgical templates with metallic sleeves for guiding drills, drill guide, and surgical accessories
7. Cross-check of dental implant positions and design of prosthodontic superstructures
8. Beginning of surgical procedure

Figures 8a–t and 9a–k represent two clinical cases of flapless guided surgery, a partial edentulous case and a complete edentulous case, respectively, with immediate loading.

The making of the surgical guides goes through many hands; an increase of the number of required steps results in an accumulation of small errors at different points: from the impressions registered to the surgical technique. According to a review of complications in guided surgery, intraoperative complications include misfit of occlusal index, difficulty in using the surgical guide because of insufficient mouth opening, misfit of the surgical template, insufficient primary implant stability resulting from soft bone, and fracture of surgical templates (Hultin et al. 2012).

Quantity and Quality of Bone

The mechanical behavior of the bone is a determining factor for successful osseointegration. The most popular method for bone quality assessment was suggested by Lekholm and Zarb, and it was a radiographic index (Lekohlm and Zarb 1985); other authors have revised the classification introducing a prognosis prediction (Misch 1990). Table 3 reports different classifications of bone quality and quantity. Lekholm and Zarb classified bone density into four categories (types I–IV), according to bone composition (the ratio between compact bone and spongy bone) and the subjective bone resistance to drilling; the presence of compact bone and bone resistance decreases from bone type I to bone type IV. Several studies have corroborated the validity of Lekholm and Zarb classification by analyzing its correlation with the outcomes of histomorphometric analysis, measurements of bone mineral density, and variables of micro CT (Bergkvist et al. 2010; Pereira et al. 2013; Ribeiro-Rotta et al. 2012).

Anitua and colleagues introduced a classification in which bone density and the thickness of the cortical bone were the two parameters helping in the determination of the diameter of the final drill before implant insertion (Anitua et al. 2015).

- Bone type 1: Bone density greater than 1000 HU and composed mostly of cortical bone (similar to Lekholm and Zarb type I bone)
- Bone type 2: Bone density of 850–1000 HU, composed of 3–4 mm-thick cortical bone surrounding a dense cancellous bone (similar to Lekholm and Zarb type II bone)

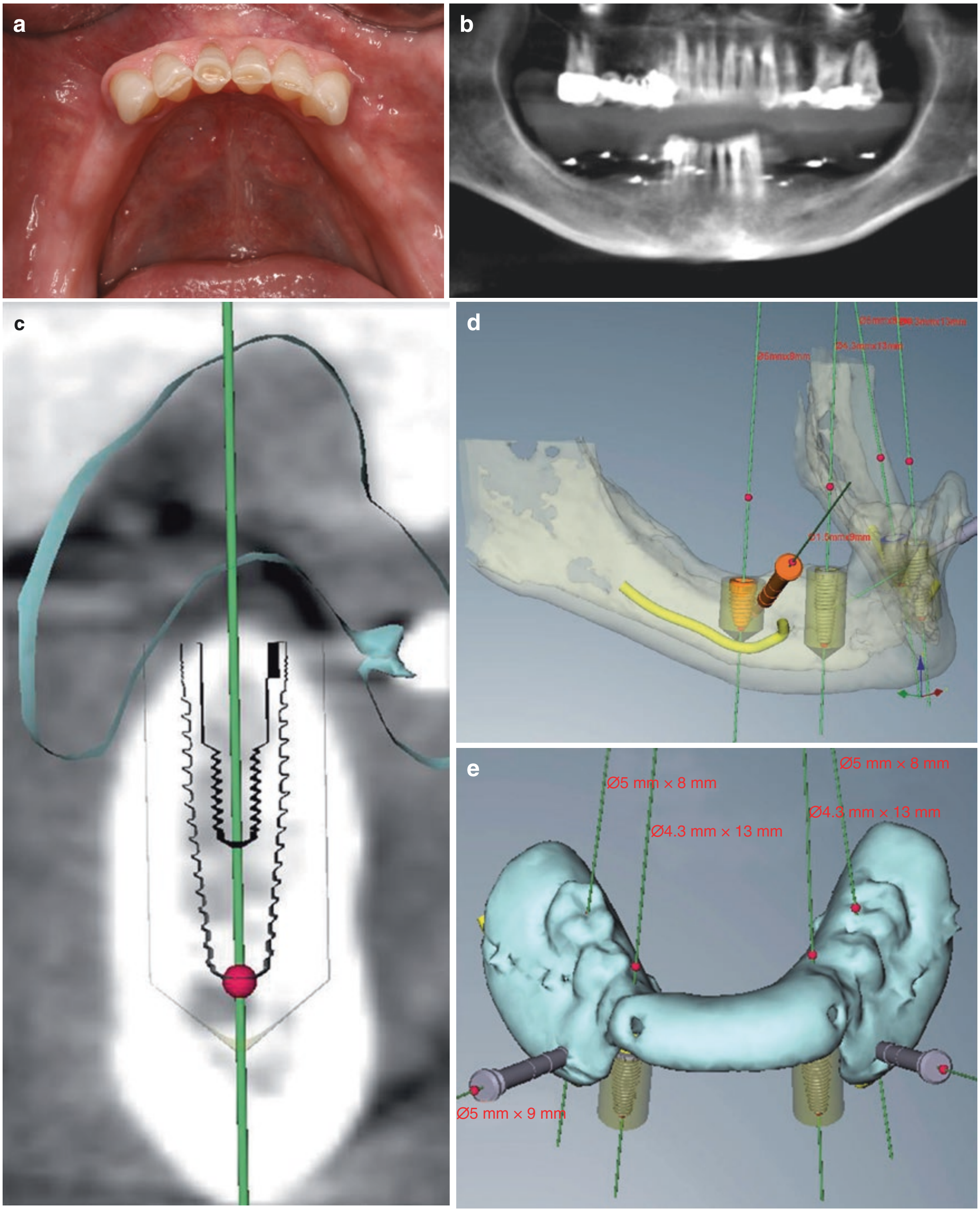


Fig. 8 (**a**) Patient with partial edentulism mandible with absence of posterior teeth. Occlusal view. (**b**) Panoramic radiograph showing the absence of both premolars and molar bilaterally. (**c**) Surgical planning with NobelGuide®; the implant was planned to have an adequate occlusal emergence, in the future prosthesis. Additionally, the implant is positioned according to the bone volume and inferior alveolar nerve to avoid its injury. (**d**) In this case, the surgical guide had teeth and mucosal support. In this case the use of bone pins is mandatory to obtain an adequate stabilization. Observe that, in case you position the pin too close or in contact to another implant, the software will alert you to change the color of the pin to orange. (**e**) Image of the surgical guide planned before send to manufacture. (**f**) Panoramic radiograph with the virtual planning. (**g**) Image of the surgical guide. (**h**) Immediate loading temporary prosthesis was made before surgery using the surgical guide. (**i**) The surgical guide was tried on in mouth and its stability and positioning is checked. To perform mini-flaps a punch was employed to paint with blue marker the implantation site of the surgical guide metal rings. (**j**) Occlusal view after marking implant position. (**k**) Mini-flaps were raised and separated using surgical sutures. (**l**) Surgical guide fixed with bone pins. (**m**) Distal implants were placed first to stabilize the guides. Implant bed was prepared with a special surgical kit. (**n**) Occlusal view after distal implant placement. (**o**) Placement of anterior implants. (**p**) Occlusal view of implants in place. (**q**) The surgical guide was removed. The mini-flaps were rolled buccally. (**r**) Implant stability quotient (ISQ) values were registered using Osstell® mentor device. (**s**) High ISQ values were obtained that allows immediate loading. (**t**) Previous confectioned provisional prosthesis was installed for immediate loading

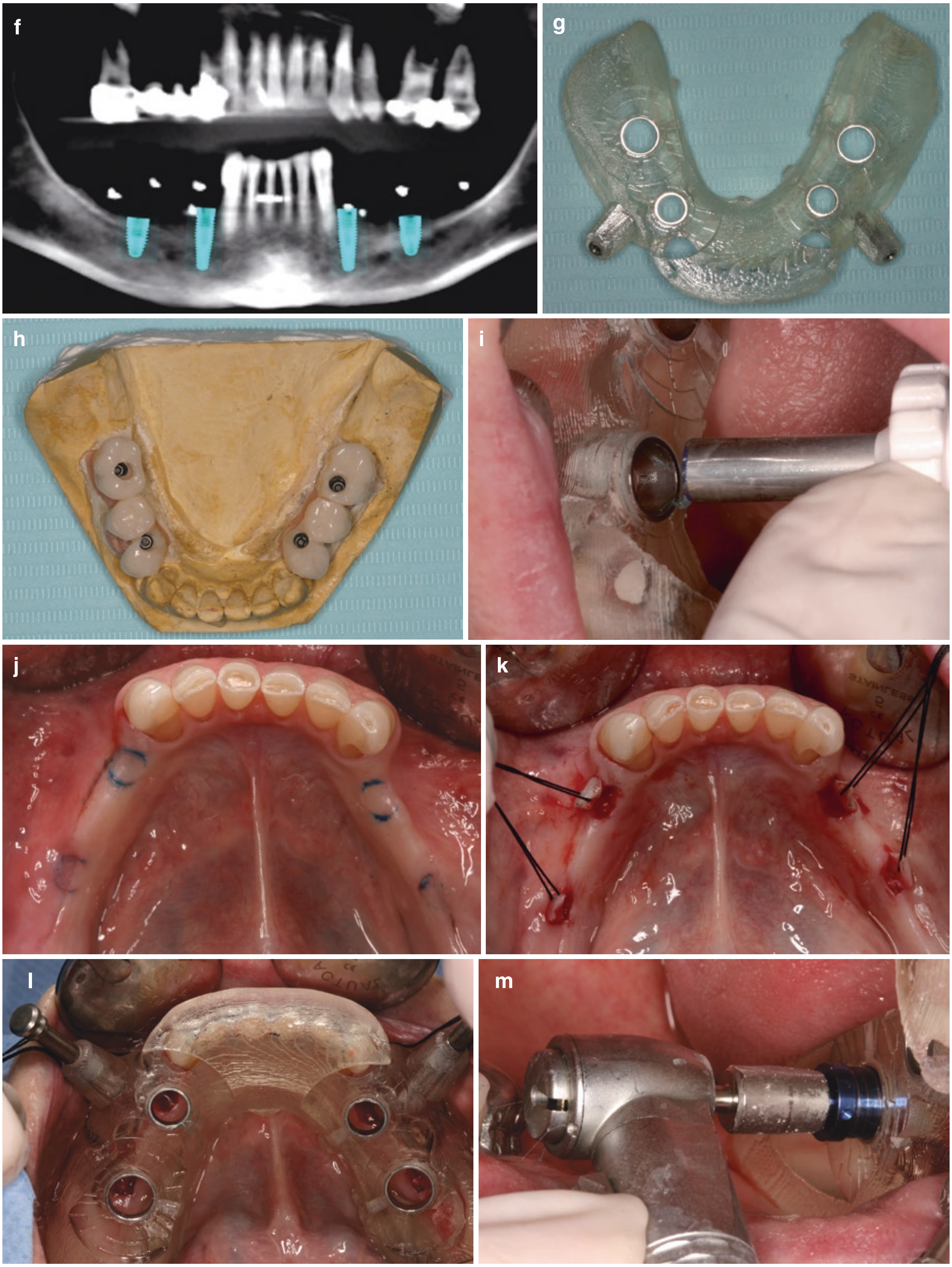


Fig. 8 (continued)

Fig. 8 (continued)

- Bone type 3: Bone density of 550 to <850 HU, composed of 2 mm-thick cortical bone surrounding a dense cancellous bone (similar to Lekholm and Zarb type III bone)
- Bone type 4: Bone density of 400 to <500 HU, composed of 0.5–1-mm-thick cortical bone surrounding cancellous bone (similar to Lekholm and Zarb type IV bone)
- Bone type 5: Bone density of 100 to <400 HU, composed mostly of cancellous bone (similar to Lekholm and Zarb type IV bone)

This classification has the merit of providing a "biologically guided" implant site preparation. Bone types IV and V

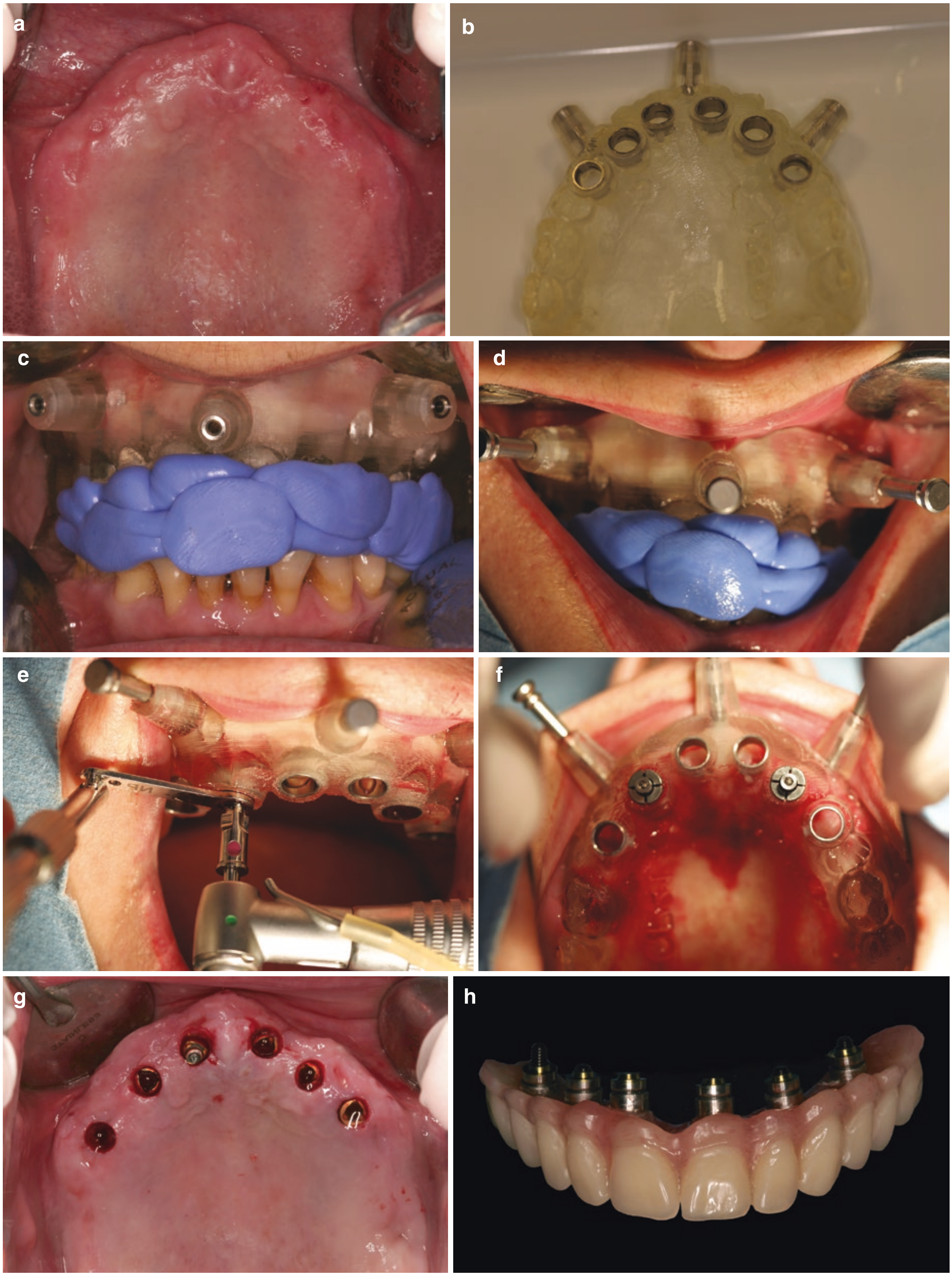


Fig. 9 (**a**) Occlusal view of edentulous maxilla. (**b**) Surgical guide prepared after virtual planning. (**c**) To correctly position the surgical guide in mouth, a silicon index was used. (**d**) To stabilize it, bone pins were used. (**e**) Implant beds were prepared through metal ring using guides with same diameter of drills. (**f**) The implants were placed in a contralateral manner, starting with the middle implants of each side to obtain a better stabilization. (**g**) Occlusal view after implant placement. (**h**) Detail of the full-arch immediate loading prosthesis, made before surgery. (**i**) Occlusal view of the temporary prosthesis in place. (**j**) Extraoral frontal view of immediate loading. (**k**) Prosthesis settlement was ascertained through panoramic radiograph

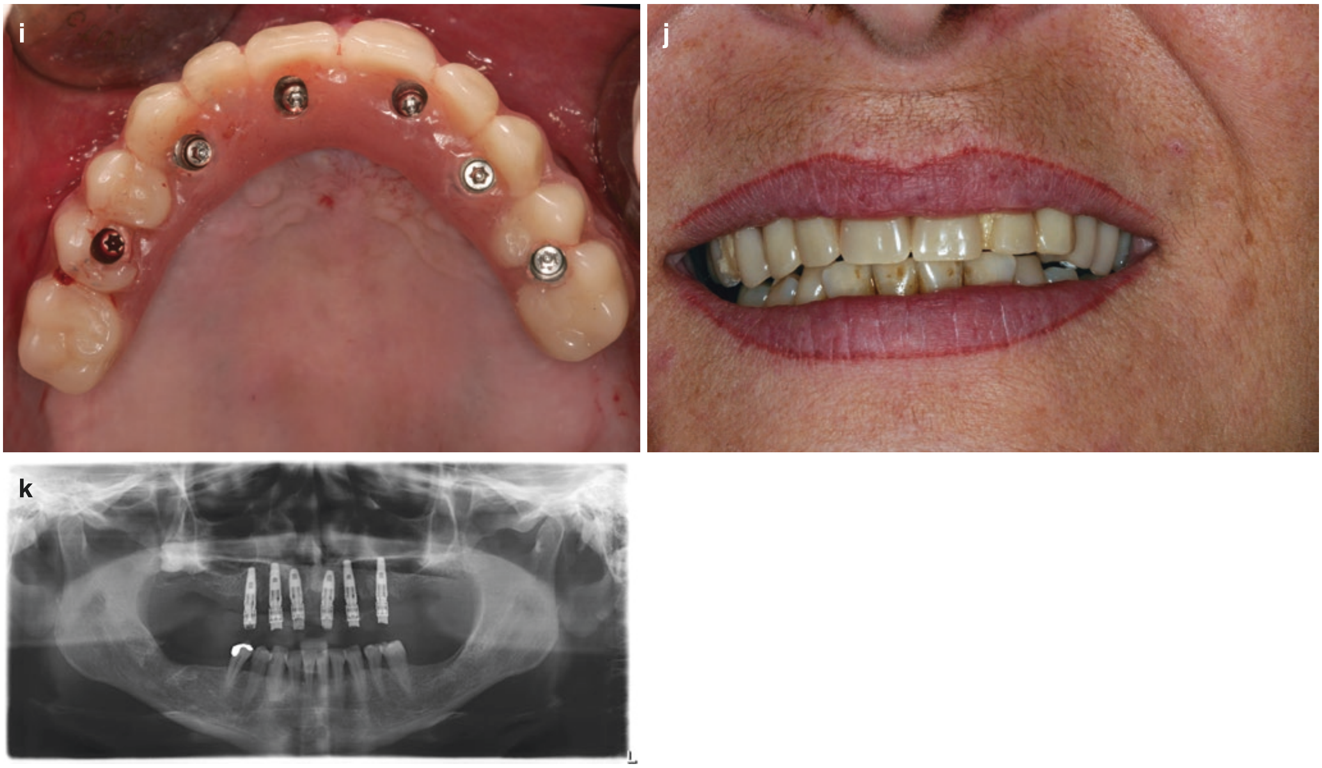


Fig. 9 (continued)

Table 3 Different classifications of bone quality and quantity

Bone density classifications		
Lekohlm and Zarb (1985)	Misch (1995)	Anitua et al. (2015)
Quality I bone: homogenous compact bone	*Class I*: dense cortical bone	*Bone type 1*: bone density greater than 1000 HU and composed mostly of cortical bone
Quality II bone: thick layer of compact bone surrounding a core of dense trabecular bone	*Class II*: porous cortical bone	*Bone type 2*: bone density of 850–1000 HU, composed of 3–4-mm-thick cortical bone surrounding a dense cancellous bone
Quality III bone: thin layer of compact bone surrounding dense trabecular bone of favorable length	*Class III*: coarse trabecular bone	*Bone type 3*: bone density of 550 to <850 HU, composed of 2-mm-thick cortical bone surrounding a dense cancellous bone
Quality IV bone: thin layer of cortical bone surrounding a core of low-density trabecular bone	*Class IV*: fine trabecular bone	*Bone type 4*: bone density of 400 to <500 HU, composed of 0.5–1-mm-thick cortical bone surrounding cancellous bone
		Bone type 5: bone density of 100 to <400 HU, composed mostly of cancellous bone

generally do not support dental implant for an immediate provisional restoration, except for the case of single implant avoiding any functional loading. When the cause of early failure is a host response, the failure rate is significantly higher for implants placed in type IV.

Generally, bone types II and III have been advocated for an immediate loading protocol by several authors (Szmukler-Moncler et al. 1998; Balshi et al. 2005): these types of bone can combine innate stabilities and good regenerative capabilities. Results are uncertain for bone type I: all the authors confirmed the attainment of immediate stability and long-term osteointegration of the placed implant; however, few of them registered a greater decrease in stability mechanically evaluated during the first month of survey.

In the preoperative classification of the type of bone by means of CT density, we suggest to control the baseline density of the empty space (about −1000 HU), of connective tissue (between 0 Hu and 250–300 Hu), and of symphyseal bone (>1000 HuU). These referring values can be left- or right-shifted, so that type of bone classification according to CT density could be accurately corrected on each patient.

Measurement of Primary Stability

It is up to the surgeon, at the very moment of implant placement, to decide whether to load immediately or not. In fact, an essential prerequisite for successful immediate loading of dental implants is the primary stability (Esposito et al. 2009; Hartog et al. 2008). Primary implant stability is the biometric

Table 4 Different classifications of bone quality and quantity

Factors affecting implant primary stability	Factors affecting implant secondary stability
Bone quantity	Primary stability
Bone quality	Bone remodeling
Surgical technique	Implant surface conditions
Implant design	Loading (correct or overload or non-homogenous load)
Implant tridimensional position	
Insertion torque	

stability achieved at the moment of implant insertion; if primary stability is reached, the implant is mechanically adapted to the host bone until the achievement of successful osseointegration (secondary stability). The success of this mechanical adaptation is a function of several factors, including features of bone surrounding the implant, implant sink depth, diameter or type of surface, and the placement technique used (Table 4).

Several invasive or noninvasive methods are employed to test the implant clinical stability: the Periotest (PT), surgical insertion torque (IT), and resonance frequency analysis (RFA) are classified among the noninvasive ones. The stiffness of the bone/implant interface can be measured with the Periotest® instrument that tests implant deflection/deceleration. A pistil from inside the instrument's hand piece repetitively performs percussions on the implant; the temporal contact between the tip of the instrument and the dental implant is measured, elaborated, and registered. However, its lack of resolution, poor sensitivity, and susceptibility to operator variability make Periotest criticizable (Meredith 1998).

It has been suggested that the measurement of the moment of force, namely, the "torque" (required for implant seating), can also be used to measure the primary stability (Trisi and Rao 1999). The determination of the insertion torque could be performed during dental implant placement by a torque gauge incorporated within the drilling unit or manually by the clinical during implant seating at the final position utilizing analogical or digital torque gauge (Barone et al. 2016). Some authors judge the insertion torque as a determinant of implant stability; moreover, a threshold of at least 30 Ncm for immediate loading protocol is suggested by most of the authors (Cannizzaro et al. 2008; Fung et al. 2011; Maló and Nobre 2008; Bogaerde et al. 2008); few authors considered sufficient an insertion torque of at least 20 Ncm in case of implants placed in a poor-quality bone or splinted together (Romanos 2009). The insertion torque registered during implant placement is important due to the selection of implant–abutment connections, which have the need of a minimal torque to engage the abutment to the implant body via the fixation screw according to the manufacturer guidelines. Even though it may seem intuitive that high insertion torque leads to better thread engagement to the bone, different pre-clinical and clinical studies have suggested that IT does not necessarily relate with primary stability (Marconcini et al. 2018). High levels of insertion torque might exceed the elastic limit of the bone causing compression necrosis and increasing the risk for marginal bone resorption. Therefore, clinicians should pay great attention to insertion torque values when performing implant site preparation for all-on-four implant-retained prostheses.

RFA device stimulates the implant body by different frequencies and monitors the stability measuring responses in terms of resonance. Two types of devices are generally used: transducer fixed to the dental implant through an integrated screw forms an implant/transducer complex that can be stimulated by means of piezoelectric crystal or magnetic pulse (Friberg et al. 1999).

The most significant factor of variability is the structure of the bone into which dental implant is placed, whereas the implant length or the position of the probe (occlusal or lateral) does not affect the RFA results (Park et al. 2010); different directional readings may, therefore, reveal more sensitive information than one-directional readings. Firmness at the implant-tissue interface is attested by the value of implant stability quotient (ISQ) units that range from 1 to 100: some authors suggested that ISQ values below 40–45 indicate a poor primary stability; however a threshold of 65 is indicated as the most favorable for implant stability (Aparicio et al. 2006). Limitation of these devices is a low ISQ value evaluation when the transducer is not well screwed on the implant body and the necessity of measurement before the final abutment and prosthetic restoration.

In summary, dental implant can be immediately loaded based on at least one of the following criteria:

- ISQ value of at least 60.
- Minimum insertion torque of 25 Ncm at the final seating of the implant.

Primary stability is heavily influenced by the surgical technique adopted. An expert surgeon might compensate for limiting factors such as type of jaw or bone quality. The immediate loading is a high-risk treatment, and just skillful surgeons could be able to identify optimal bone conditions under which patients can be treated conventionally. When the bone is of good quality, a progressive thread design seems to decrease the compression of the crestal bone preventing bone loss (Romanos and Nentwig 2009). For implants placed in unfavorable bone quality, an improvement of bone density and so the primary (mechanical) stability could be achieved by bone condensing or under-preparation of the osteotomy sites.

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Part III

Immediate Restoration

Single- and Partial Multiple-Unit Provisional Restorations in the Esthetic Area

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Abbreviations

3D	Three-dimensional image
BOPT	Biologically oriented preparation technique
CAD/CAM	Computer-aided design/Computer-aided manufacturing
CaP	Calcium/phosphate bioceramics
CBCT	Cone beam computed tomography
HA	Hydroxyapatite
STL	Standard template library

Chapter Resume
This chapter seeks to provide a concise description of the importance and types of provisional restorations available when following an immediate provisionalization approach in the esthetic area and also includes a series of cases described in a step-by-step sequence. These cases are intended to allow the reader to follow the steps understanding the reasons behind them in a continuous and focused way, with a total of 59 images describing the clinical scenarios from the initial situation to final outcome.

Take-Home Messages
Provisional restorations are described as interim prosthesis placed to provide both esthetic and functional benefits until the moment of delivery of the final prosthesis.

Benefits, limitations, and nomenclature regarding the different types of provisional restorations can seem cumbersome. However, their knowledge is important in order to achieve the desired optimum outcome.

Different clinical approaches can be followed in the design and fabrication of the provisional restorations. When indicated, immediate implant-supported provisional restorations are considered the first choice under the different steps of the selection process as they will provide the greater esthetic and functional benefits.

The provisional restoration can also be used as a diagnostic tool that will help the patient, clinician, and dental technician evaluate the future outcome of the definitive restoration.

The influence of the subgingival portion in implant-supported provisional restorations on the final outcome must not be underestimated as it will be able to define both the anatomy of the clinical crown and the appearance of the underlying soft tissues.

Introduction

The immediate implant-supported provisional restoration in the partially or totally edentulous patients is a predictable and well-accepted procedure in dentistry. The Glossary of Prosthodontic Terms defines a provisional prosthesis as a prosthesis designed to improve or evaluate esthetics, speech, and occlusal function in a period of time between implant placement and final restoration with a definitive prosthesis (Driscoll et al. 2017). Planning and design should always take place during the pre-surgical phase of treatment and constitute a tool for communication among the members of the team, which in most cases is of a multidisciplinary nature (prosthodontist, surgeon, dental technician, and patient).

The requirements of a provisional prosthesis are the same as those of any other dental prosthesis, i.e., it should be functional and esthetic and must not create problems for the

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correct osseointegration of the dental implant. The material chosen for the provisional prosthesis depends on its physical properties, handling characteristics, esthetics, durability, and costs among others. In selecting one design or another, Priest (2006) considered that eight criteria must be taken into account in order to offer the best solution for each individual case: esthetics, patient comfort, treatment time, laboratory costs, occlusal space, easy removal, durability, and easy modification.

In seeking to improve esthetics, the provisional prosthesis moreover allows us to guide the conformation of the gingival tissue contour during the different healing phases after tooth extraction and/or implant placement. This conformation should allow a good transition between the gums and the prosthetic reconstruction, with the purpose of ensuring an outcome as natural as possible. The provisional prosthesis is most often ovoid in shape, maintaining or improving soft tissue morphology, but this does not imply that such a design is to be used on a systematic basis.

Classification of Provisional Restorations

In implantology, provisionalization can be classified according to the timing of placement, function, type of edentulism, and the ability of the patient to remove the prosthesis:

Timing of Placement

The classification of provisionalization according to the timing of placement refers to whether it is performed before or after the surgery in which the dental implants are placed—though it must be remembered that planning must always be made before surgery.

Provisional prostheses placed before implant surgery are used until the time of implant placement by patients due to esthetic purposes or in order to preserve a correct gingival contour in the event of recent extractions. The prostheses may be removable or fixed to the teeth located adjacent to the edentulous segment.

Postsurgical provisional restorations in turn are placed after implant placement. Thus, conditioned to the surgical and loading protocol involved, the design of the provisional prosthesis will differ depending on the clinical situation.

In turn, when provisionalization is performed after the placement of dental implants and the prosthesis is retained by them, fitting of the provisional restoration may be immediate, early, or deferred. Immediate provisionalization is defined as fitting of the provisional prosthesis until 7 days after implant placement, while early provisionalization is defined as fitting of the prosthesis after this period but before the osseointegration is complete. Deferred provisionalization is consistent with the conventional loading protocol, in which the implant remains free from loading for over 2 months (Esposito et al. 2013), and is therefore performed after the implant osseointegration period.

The decision to perform immediate, early, or deferred provisionalization is conditioned to the primary implant stability achieved at surgery, the position of the peri-implant gingival tissue, and the morphology of the bone surrounding the implant site.

Function

Two types of immediate loading have been described in the literature: (a) functional or occlusal immediate loading and (b) nonfunctional or non-occlusal immediate loading. Functional or occlusal immediate loading refers to the use of a provisional or definitive prosthesis placed on the day of surgery and in contact with the opposing or antagonist arch (Degidi and Piattelli 2003). In contrast, nonfunctional or non-occlusal immediate loading involves modification of the immediate provisional restoration in order to prevent occlusal contacts in centric and lateral excursive movements—thus avoiding the risk of mechanical overloading by functional or parafunctional forces (Misch 1998) although it should also be stated that these terms can be misleading, however, since "immediate provisionalization" does not prevent the restoration from being functional (Roccuzzo et al. 2018). Nonfunctional immediate loading is suggested by the authors for single anterior restorations, while functional immediate provisionals are suggested for partial and full arch clinical scenarios. However, Lideboom et al. observed no radiological or esthetic differences after 1 year of follow-up between single maxillary implants subjected to "immediate provisionalization" and implants subjected to "immediate loading."

Depending on the clinical situation, both types of immediate restoration serve to maximize esthetics and help secure an adequate prosthetic emergence profile, particularly at post-extraction implant sites (Locante 2001). In this regard, it must be taken into account that careful optimization of the emergence profile at the abutment/restoration interface is decisive for ensuring a good definitive appearance of the prosthesis (Steigmann et al. 2014).

Type of Edentulism

Depending on the type of edentulism involved, provisionalization can be defined as full arch (fully edentulous arch), partial (partially edentulous arch), or single (a subgroup of partial provisionalization in which a single implant is provisionalized). In line with the objectives of this chapter, we will exclusively focus on the provisionalization of partially edentulous arches and single units.

Ability of the Patient to Remove the Prosthesis

Depending on the ability of the patient to remove the prosthesis, provisional restorations are classified as either removable or fixed.

Removable Provisional Restoration

Traditional removable provisional restorations are made of conventional acrylic or composite resins. Their advantages include particularly low costs and easy fabrication and fitting. Their disadvantages include an inherent risk of negatively affecting the osseointegration process, esthetic limitations and probable patient discomfort, and functional limitations. The reason why provisional restorations of this kind can affect osseointegration is because their gingival portion may transmit uncontrolled loading forces to the implants in situations where the prosthesis comes too much in contact with the soft tissues, giving rise to peri-implant tissue loss (Bergkvist et al. 2008).

An alternative to the use of a conventional removable partial prosthesis is the application of an Essix retainer (Moskowitz et al. 1997). This design consists of an acetate splint made in the laboratory using a vacuum technique, where a composite filling or acrylic tooth is placed in the edentulous zone, avoiding excessive contact with the gingival tissue. Such removable prostheses are usually indicated for short periods of time and/or in cases of limited interocclusal space.

Fixed Provisional Prosthesis

Fixed provisional prostheses are prostheses that cannot be intentionally removed by the patient. Two subgroups can be established: implant-supported fixed provisional prostheses and tooth-supported (i.e., non-implant-supported) fixed provisional prostheses.

Implant-Supported Restoration

Provisional fixed implant-supported restorations are provisional prostheses directly fixed onto the implant by means of a provisional abutment. Priest (2006) considered that although peri-implant soft tissue maturation can be achieved with ovoid pontics, direct provisional restoration over implants is the most effective strategy. We consider this type of provisional restoration to be the first-choice option in cases characterized by strong esthetic demands. Nevertheless, a number of criteria must be met in order to ensure success with these restorations: sufficient primary implant stability must be ensured (Becker et al. 2011), with adequate general health of the tissues in the zone and with no important initial discrepancy between the height of the gingival margin and the adjacent teeth (Santosa 2007).

Correct occlusal fit of the prosthesis over implants is essential for implant-based treatment success. Some authors advise light occlusal contact in cases of immediate loading of multiple splinted implants. However, in the case of immediate loading of single implants, occlusal contacts in centric and excursive movements (protrusive and lateral) are to be avoided (Siadat et al. 2017). For this reason, provisional restorations in infraocclusion are recommended (Schnitman et al. 1997).

Depending on the way in which the prosthesis is placed on the provisional abutments, fixed implant-supported restorations can be subdivided into cement-retained or screw-retained prostheses according to the clinical situation of the patient and the preferences of the clinician.

Cement-Retained Restoration

Cemented provisional restorations are advised for esthetic reasons in clinical situations where implant angulation does not allow the fitting of a screw-retained provisional prosthesis with palatine/lingual access (Chee et al. 2018). Special care is required with these provisional restorations to not leave traces of cement in the subgingival zone and/or in contact with other tissues such as bone graft or connective tissue, since this could favor increased bacterial contamination of the peri-implant sulcus and adversely affect the final outcome. Subgingival margins are therefore to be avoided.

Screw-Retained Restoration

Screw-retained provisional restorations eliminate the risk of cement accumulation in the subgingival portion (Wittneben et al. 2013) and make it easier to place and remove the implant—this being very important for the conformation of an adequate emergence profile. In contrast, the use of a screw-retained provisional prosthesis implies increased bacterial contamination in the internal portion of the connection compared with a cement-retained provisional restoration (Penarrocha-Oltra et al. 2016).

Tooth-Supported Restoration

Following implant placement we can fit a Maryland (Livaditis and Thompson 1982) provisional prosthesis with an ovoid pontic (Liu 2004), or, when having to crown the teeth adjacent to the implant (Zitzmann et al. 2002), a fixed partial bridge over the previously trimmed abutments can be fitted. As commented above, the surface of the prosthesis should not establish too much contact with the peri-implant soft tissues or healing abutment during the osseointegration period. With regard to the Maryland bridge, its minimally invasive character constitutes an advantage, though its strong tendency toward decementation and its limitations for use in

Table 1 Modification of crown contour to optimize the soft tissue profile (Priest 2006)

Emergence profile	Crown contour
Raise gingival margin apical	Increase buccal convexity
Lower gingival margin coronal	Reduce buccal convexity
Raise papilla apical	Reduce proximal contours
Lower papilla coronal	Increase proximal contours

patients with excessive overbite or parafunctional habits are regarded as disadvantages.

Importance of the Provisional Restoration

In recent years esthetics have become a primary concern in dental treatments for both clinicians and patients. Provisional restorations may serve as diagnostic prostheses to evaluate the outcome of the definitive restoration. They allow the patient and clinician to visualize a condition very similar to the final outcome and thus establish an opinion. However, esthetic success in implantology is not only conditioned by the shape, color, contour, and naturalness of the prosthesis as such but also by the topography and appearance of the soft tissues. One of the most important functions of provisional restorations in implantology is therefore to serve as a guide for conformation of the soft tissue contour. In order to understand the role of the provisional prosthesis over implants in relation to the soft tissue contour, we first must describe terms such as the emergence profile and the interdental papilla.

The emergence profile is the part of the prosthesis that will define the gingival contour of the restoration and extends from the gingival margin to the most coronal portion of the implant neck. Because of its location, this portion largely conditions the final esthetic outcome of the individualized restoration; it is therefore advisable to conform and remodel it through personalization of the provisional prosthesis. Personalization requires us to define two zones along the emergence profile: the critical contour and the subcritical contour (Su et al. 2010). The critical profile is defined as the profile close to the gingival margin. Alterations of the critical profile will modify the morphology of the clinical crown. The subcritical contour in turn extends between the critical profile and the coronal portion of the implant neck. Alterations of the subcritical profile will modify gingival tissue tone and may help us to simulate the presence of the root of the tooth we are replacing (Table 1).

The interdental papilla was described by Cohen (1967) as a series of buccal and lingual peaks of keratinized tissue with interproximal zones of nonkeratinized or parakeratinized tissue. The interdental papilla is not only regarded as a biological barrier that protects the periodontal structures but also as a marker of dental esthetics, since a deficient or missing papilla gives rise to a black tone that poses a great esthetic problem. At present, preservation of the morphology of the interdental papilla in the anterior sector poses an esthetic challenge in implant-supported restoration treatments. Tarnow et al. (2003) reported that the average height of the papilla between two implants is less than that found between natural teeth and that the height is moreover influenced by the presence and dimensions of the interproximal bone.

Treatment Sequence in Immediate Provisionalization

Cement-Retained Single-Unit Provisional Restoration: Dr. Rubén Agustín

See Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28.

Fig. 1 Pre-treatment view showing the erythematous and retracted gingival zone corresponding to the left upper central incisor (2.1) carrying a buccal ceramic veneer

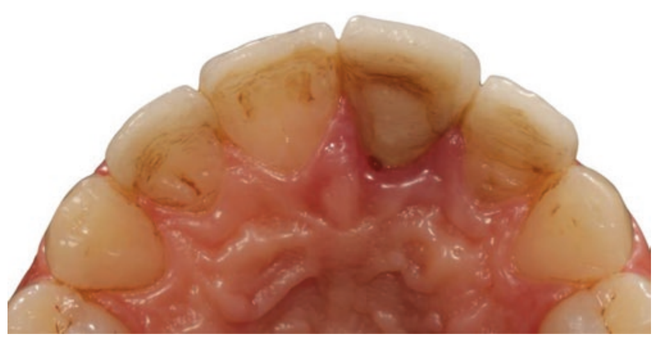

Fig. 2 Pre-treatment occlusal view. The palatine mucosa corresponding to the left upper central incisor appears edematous and inflamed

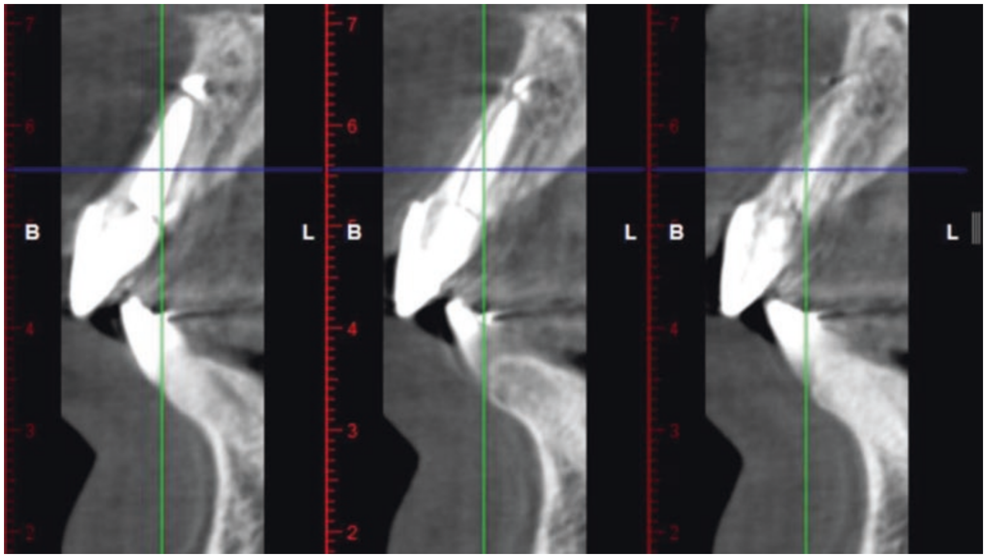

Fig. 3 Pre-treatment cone beam computed tomography (CBCT) view. Vertical root fracture of 2.1 is observed, with absence of the buccal cortical component

Fig. 4 View of the fractured tooth after removal

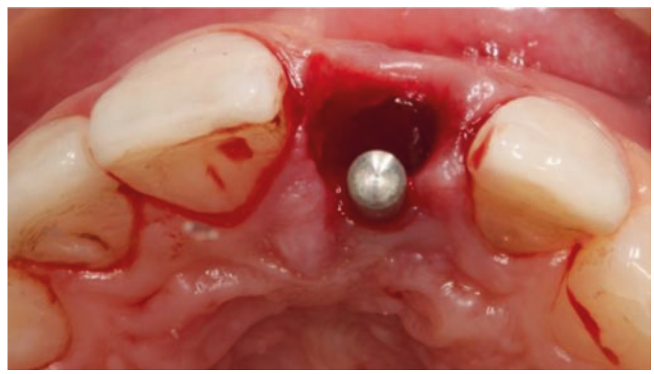

Fig. 6 Occlusal view of the surgical implant bed

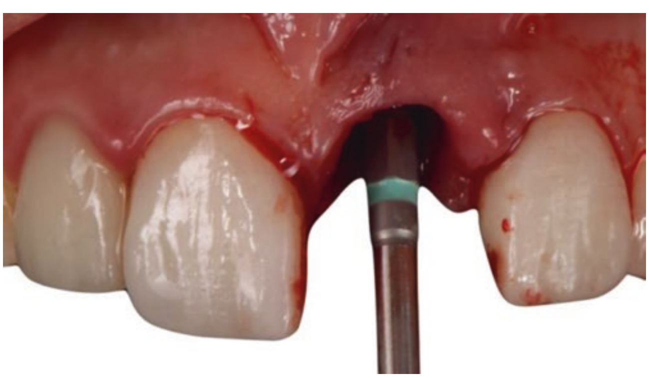

Fig. 5 Buccal view of the surgical positioner for checking bone drilling to secure correct implant placement

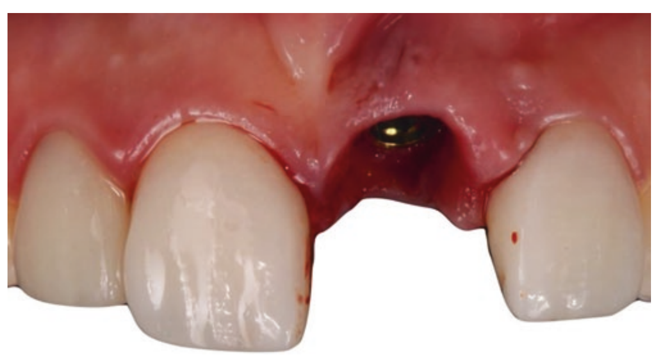

Fig. 7 Buccal view of the tissue level of the converging collar implant (PRAMA. Sweden & Martina) placed in the post-extraction site

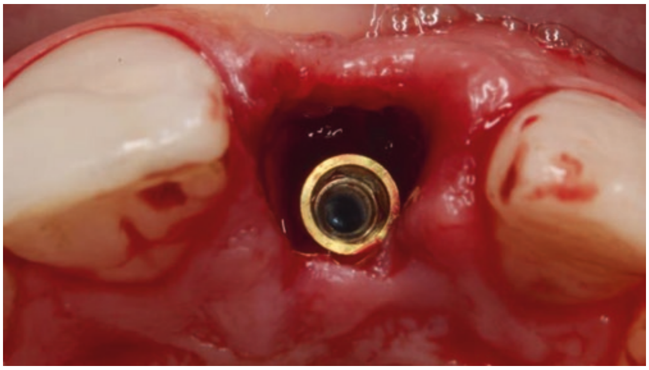

Fig. 8 Occlusal view of the implant placed in the palatine zone of the post-extraction site

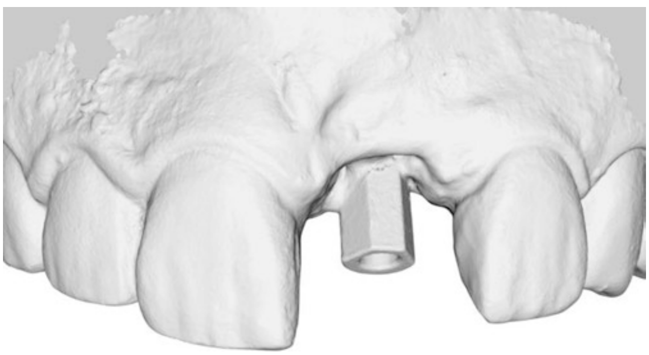

Fig. 9 Digital scan (STL) of the scan body over implant after placement of the latter

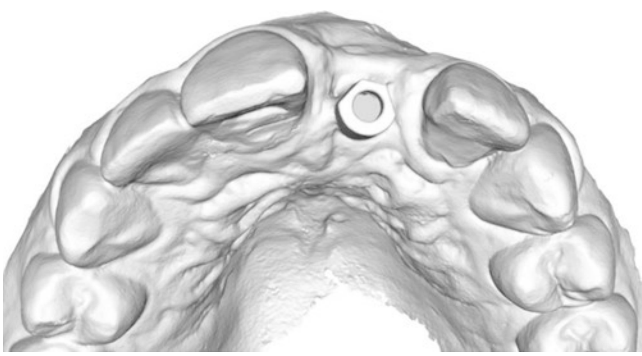

Fig. 10 Occlusal view of the digital scan of the implant to fabricate the immediate loading provisional cement-retained crown and abutment

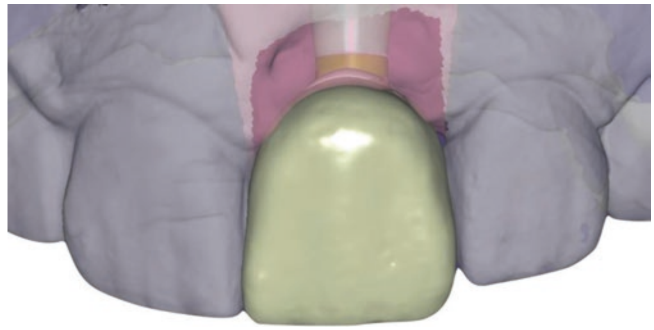

Fig. 11 Virtual design of the resin crown and titanium abutment of the immediate loading provisional cement-retained prosthesis

Fig. 12 Stereolithographic resin model after fabrication with a 3D printer

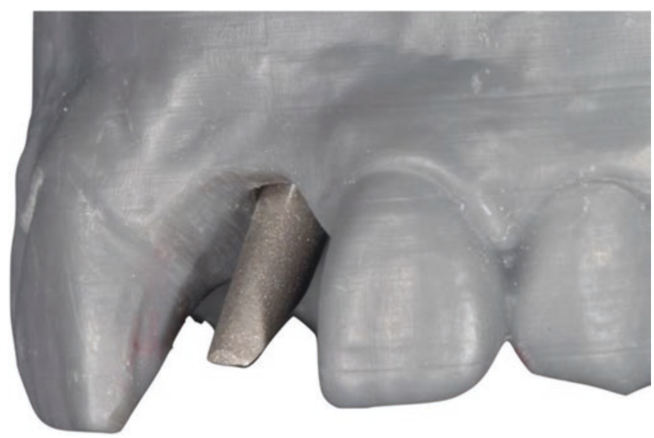

Fig. 13 Titanium abutment without finishing line (BOPT), fabricated using CAD/CAM technology

Fig. 14 Immediate loading provisional cement-retained resin crown (fabricated from resin blocks drilled with the CAM machine)

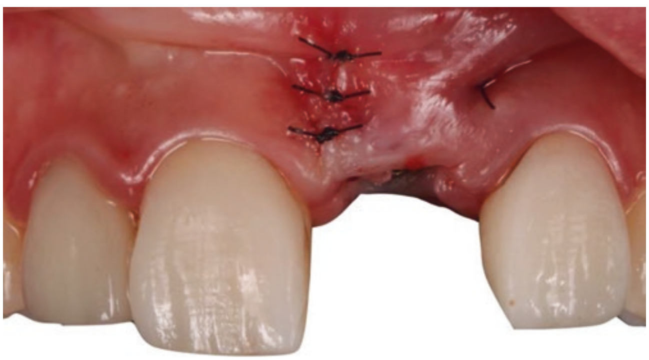

Fig. 15 Placement of a connective tissue graft buccal to the socket to correct the volume defect in the buccal area

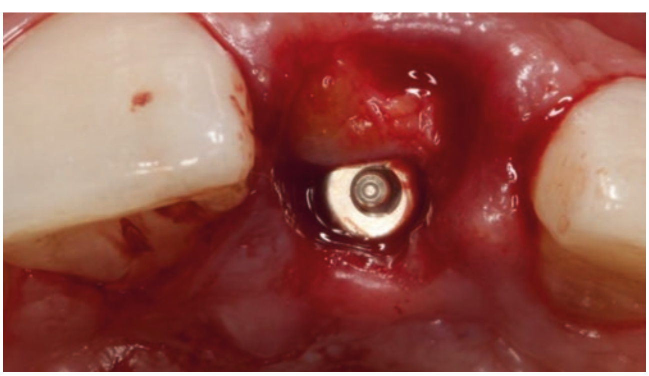

Fig. 16 Occlusal view of the location of the connective tissue graft

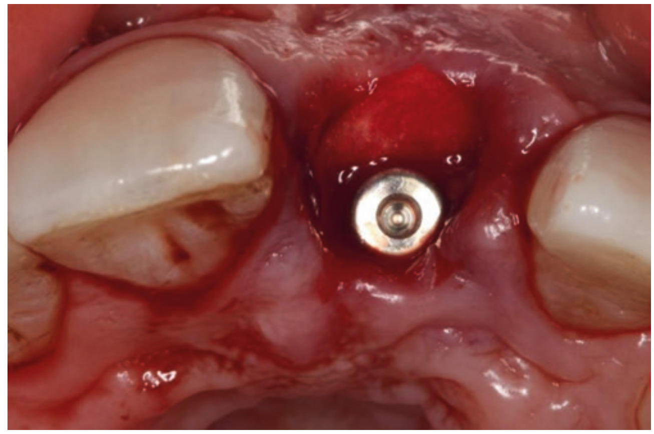

Fig. 17 View of the collagen membrane positioned palatine to the connective tissue graft, acting as a barrier between the soft tissue graft and bone. This allows placement of the synthetic bone graft in the buccal area of the exposed implant in order to regenerate the lost buccal bone

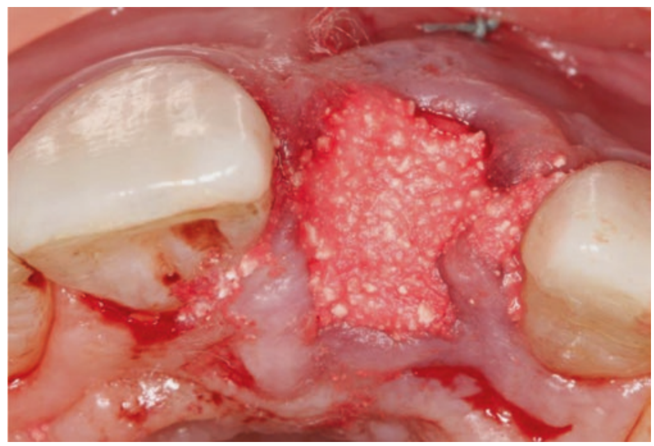

Fig. 18 Occlusal view of the synthetic bone graft (Maxresorb® Inject. Active nano-HA, Biphasic Ca/P and HA)

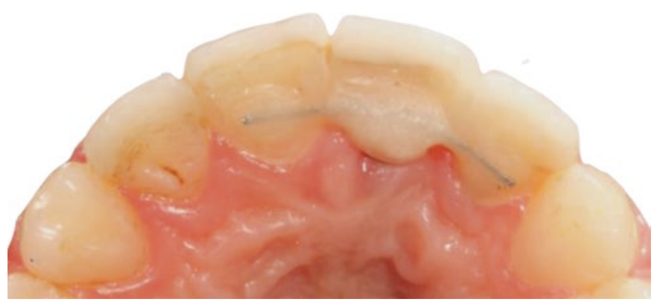

Fig. 19 Placement of an esthetic immediate loading implant-supported fixed Maryland bridge carried by the patient during the first 48 h until the CAD/CAM immediate loading prosthesis has been prepared

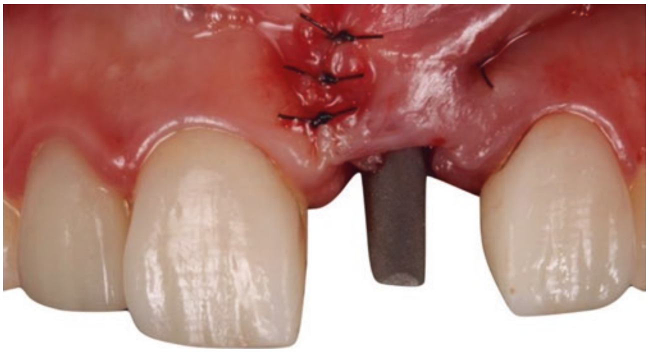

Fig. 20 Buccal view of the titanium abutment 48 h after implant placement surgery

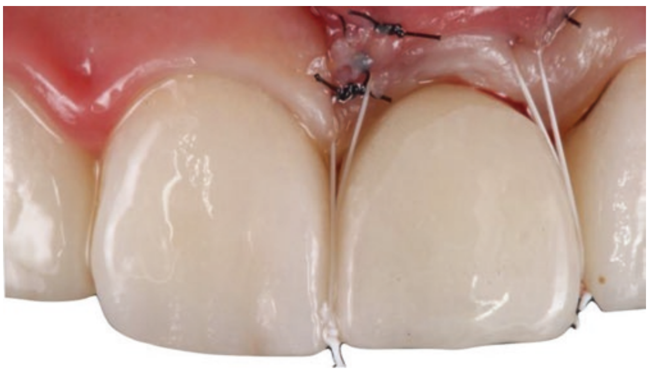

Fig. 21 Buccal view of the cement-retained provisional resin crown on the titanium abutment using TempBond Clear™ (Kerr Dental) provisional cement

Fig. 22 Healing of the keratinized mucosa of the implant 15 days after surgery

Fig. 23 Lateral view of the keratinized mucosa of the implant 10 weeks after surgery

Fig. 24 Occlusal view of the keratinized mucosa after implant osseointegration

Fig. 25 Buccal view of the definitive lithium disilicate cement-retained prosthesis

Fig. 26 Posttreatment buccal view 2 weeks after placement of the ceramic cement-retained crown on the implant of 2.1 and replacement of the ceramic veneers on the rest of the upper incisors (1.1, 1.2, and 2.2)

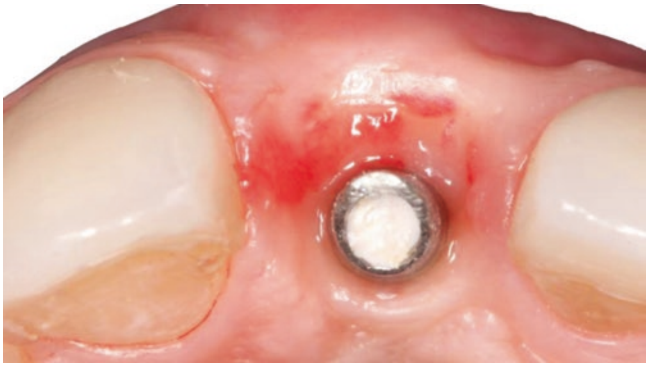

Fig. 27 Occlusal view of the keratinized mucosa around the titanium abutment 2 weeks after placement of the definitive ceramic crown

Fig. 28 Radiographic view of the implant-abutment-crown unit 10 weeks after implant surgery

Screw-Retained Single-Unit Provisional Restoration: Dr. Arturo Llobell

See Figs. 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, and 50.

Fig. 29 Initial situation presents a fractured tooth #21 with a coronally positioned gingival margin as well as translucency of the darkened root portion through the gingival tissue

Fig. 30 Initial situation presents a fractured tooth #21 with a coronally positioned gingival margin as well as translucency of the darkened root portion through the gingival tissue

Fig. 31 Initial situation presents a fractured tooth #21 with a coronally positioned gingival margin as well as translucency of the darkened root portion through the gingival tissue

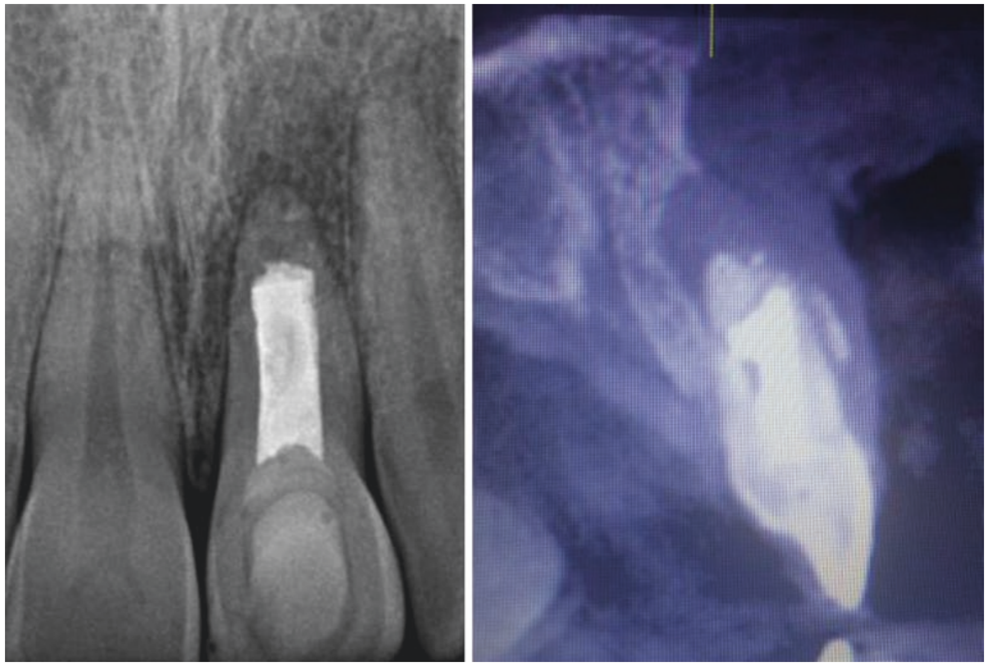

Fig. 32 Periapical radiograph and cone beam computed tomography (CBCT) reveal an alveolar defect (fenestration) on the apical position of the tooth root

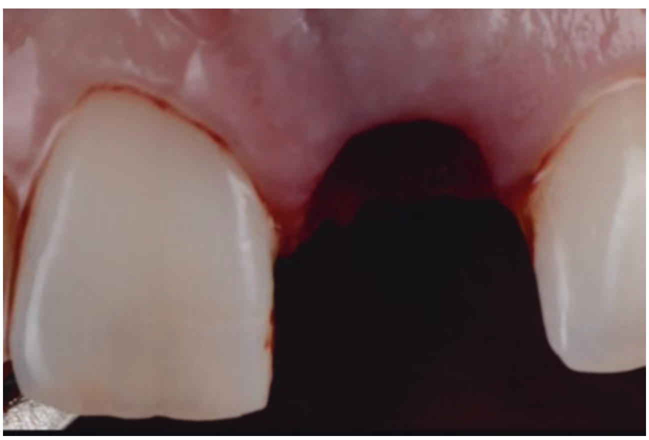

Fig. 33 Atraumatic extraction performed maintaining an intact gingival architecture and blood supply

Fig. 35 Fabrication of the screw-retained immediate implant provisional restoration with a slight concave subgingival profile

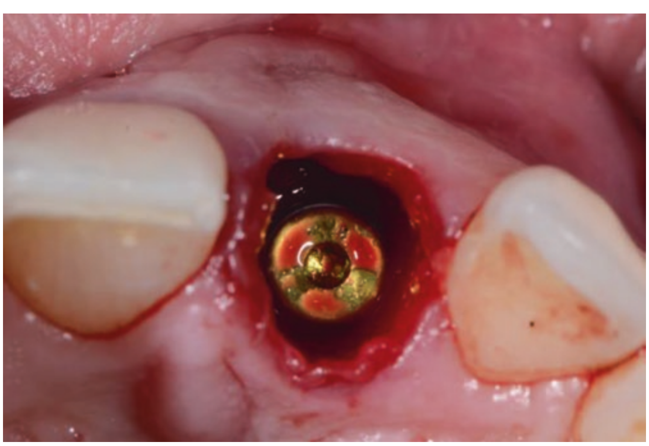

Fig. 34 Flapless implant placement (Nobel Active) in a palatal position leaving a buccal gap that will be filled with a xenograft

Fig. 36 Placement of the xenograft (Bio-Oss, Geistligh Pharma AG) after implant placement and provisional fabrication on the buccal gap between the implant and remaining alveolar bone

Fig. 37 Placement of the immediate provisional restoration following the gingival contours of the pre-existing tooth that was extracted and a concave subgingival profile, sealing the extraction site with the implant and xenograft

Fig. 38 Clinical situation 3 months after the surgical phase was performed

Fig. 39 Gingival contours 3 months after the surgical phase was performed

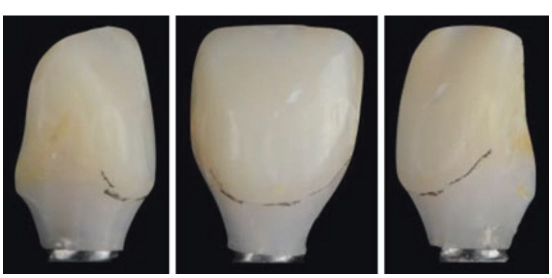

Fig. 40 Outline of the gingival margin

Fig. 41 Contour modifications using composite resin (Tetric EvoCeram Ivoclar Vivadent) in order to achieve a more desirable gingival morphology

Fig. 42 Clinical situation and gingival morphology after contour modifications

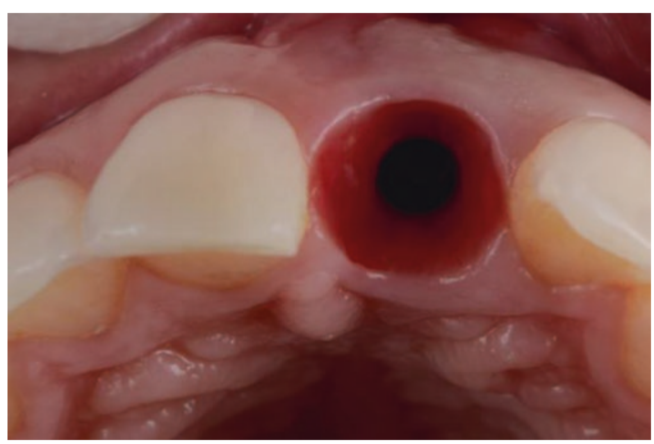

Fig. 43 Clinical situation and gingival morphology after contour modifications

Fig. 44 Fabrication of a customized impression coping following the contours achieved in the provisional restoration

Fig. 45 Fabrication of a customized impression coping following the contours achieved in the provisional restoration

Fig. 46 Fabrication of a customized impression coping following the contours achieved in the provisional restoration

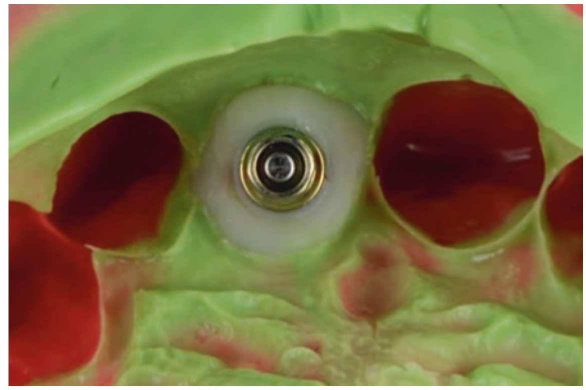

Fig. 47 Open tray final impression using an addition silicone (Elite HD+, Zermack)

Fig. 48 Final screw-retained prosthesis fabricated in zirconia with layered feldespathic porcelain in the buccal aspect to improve the esthetic outcome. Connection to the implant is made with the use of a titanium cylinder (Nobel Biocare)

Fig. 49 Final outcome, 20-month follow-up

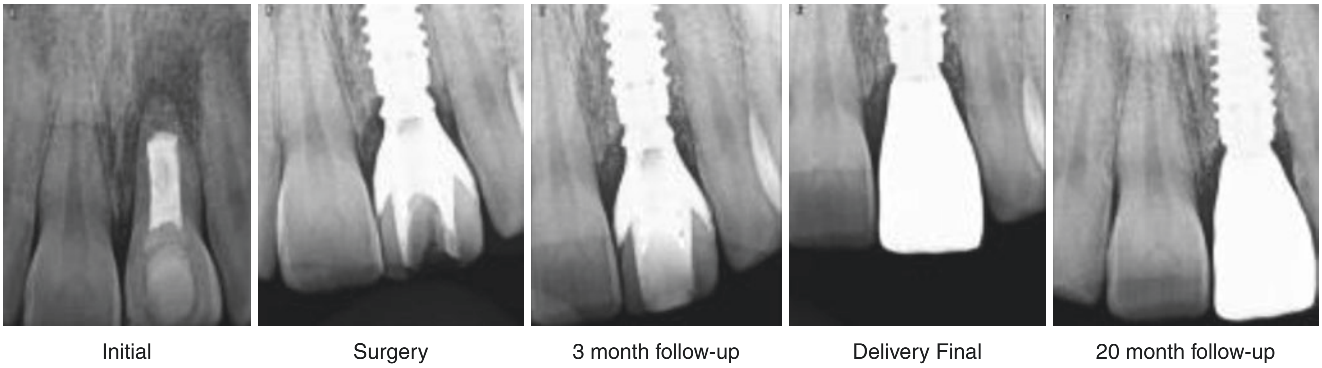

Fig. 50 Radiographic analysis through the different treatment phases

Fig. 51 Initial situation of the lower anterior teeth presenting significant bone loss and malposition

Fig. 53 Clinical situation after tooth extraction

Fig. 52 Initial situation of the lower anterior teeth presenting significant bone loss and malposition

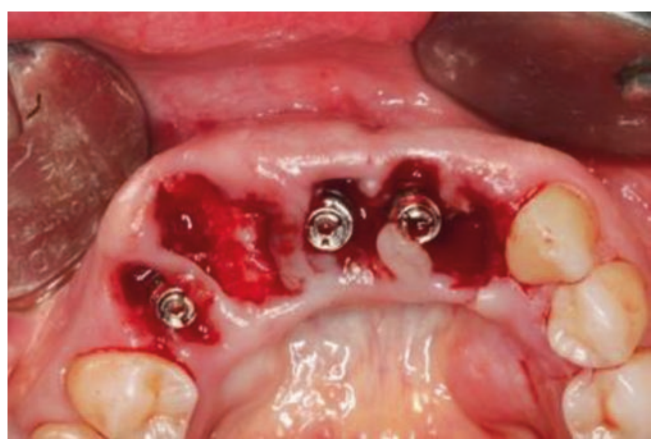

Fig. 54 Clinical situation after implant placement (Phibo TSA®)

Partial Multiple-Unit Immediate Provisional Restoration: Drs. Miguel and David Peñarrocha

See Figs. 51, 52, 53, 54, 55, 56, 57, 58, and 59.

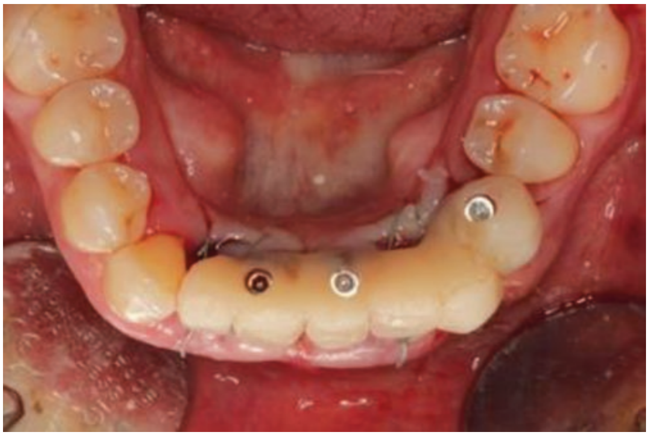

Fig. 55 Immediate fixed screw-retained provisional restoration on the day of surgery

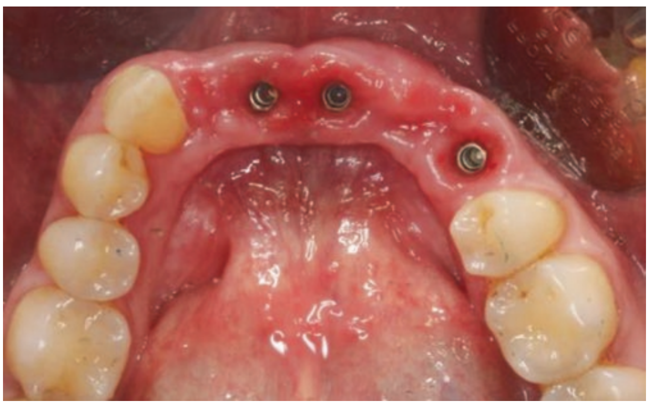

Fig. 56 Immediate fixed screw-retained provisional restoration after healing period

Fig. 57 Healing of the gingival tissue around the implants

Fig. 58 Clinical situation of the final restoration

Fig. 59 Clinical situation after delivery of the final restoration

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Immediate Loading with Fixed Full-Arch Prosthesis in the Edentulous Patient: Treatment Protocol

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Abbreviations

CCD Charge-coupled device
ISQ Implant stability quotient
Ncm Newton/centimeter
STL Stereolithography

Take-Home Message
The surgical technique for immediate loading in the edentulous patient involves a series of adaptations to improve the result such as regularization of the alveolar ridge through osteoplasty and the use of methods to enhance primary stability.

There are two main protocols to obtain temporary immediate loading full-arch prosthesis, the chairside or direct technique, in which a conventional denture is adapted immediately after placing the implants, and the laboratory or indirect technique, in which impressions and bite registrations are obtained after implant placement and the laboratory fabricates the immediate loading prosthesis within several days.

New devices specifically designed for immediate loading and digital technologies will facilitate and make more predictable treatment option.

Surgical Protocol

Incision and Flap Design

Immediate loading with fixed full-arch prosthesis in edentulous patients may be performed in the maxilla and/or in the mandible.

In a maxilla case, a common approach is to perform a crestal incision and two distal-releasing incisions. The primary crestal incision is often made slightly palatal to increase the amount of keratinized mucosa in the vestibular area of the implants. In cases in which osteoplasty is not necessary in the midline, two independent trapezoidal flaps can be used in the first and second quadrants.

In a mandibular case, the central incision may be accompanied by a central vestibular-releasing incision yielding two triangular flaps or two distal-releasing incisions that provide a trapezoidal flap. Distal-releasing incision must avoid the emergence of the mental nerve, which in jaws with severe bone reabsorption can be very superficial.

The incisions and full-thickness flap elevation are usually done once the teeth are extracted (Figs. 1a, b and 2).

In a small number of cases, when both the bone and keratinized mucosa are abundant, immediate loading can be performed using a flapless approach (Fig. 3a, b). The advantages of not raising a mucoperiosteal flap are reduced surgery times, fewer postoperative complications such as pain and bleeding, and greater patient comfort (Arisan et al. 2010). Moreover, recent studies have found better healing and lower rates of alveolar and peri-implant bone loss when using this technique (Covani et al. 2014; Barone et al. 2014). The use of guided surgery can facilitate performing a flapless implant surgery as it allows to maximize the use of the available bone without having to visualize it directly (Fig. 4a–q). However, very often a flapless technique cannot be applied—even with guided surgery—because it is necessary to perform bone regeneration and ridge osteoplasty or change the position of the keratinized mucosa with respect to the implants.

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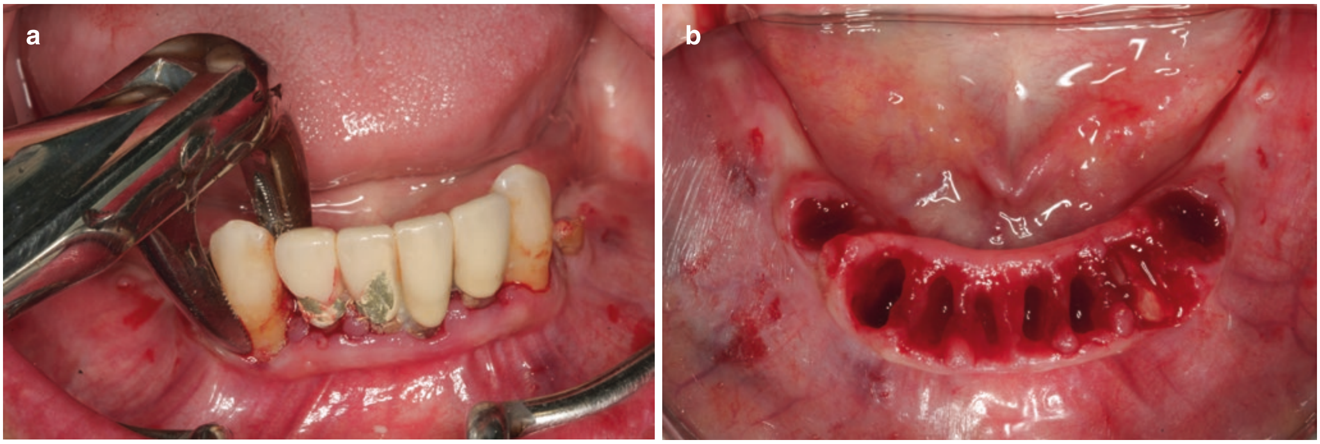


Fig. 1 (**a**) Extraction of the remaining mandibular teeth due to advanced periodontal bone loss in a patient planned for immediate loading. (**b**) The extractions are performed atraumatically

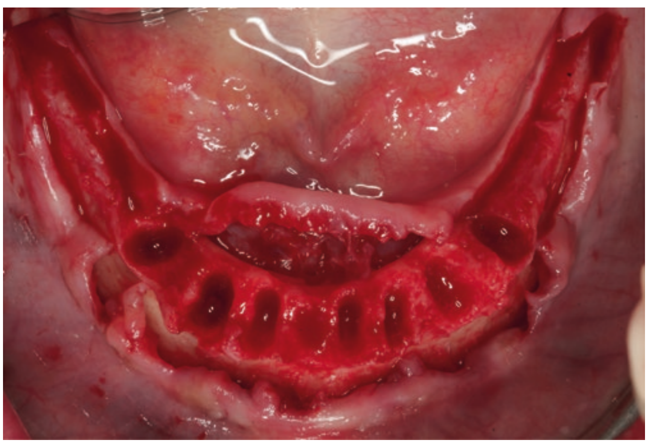


Fig. 2 A full-thickness flap is lifted

Osteoplasty

The bone crest should have a uniform height to allow a cleansable prosthetic design. Moreover, the bone ridge should have ideally a width of at least 6 mm to place standard diameter implants completely surrounded by at least 1 mm of the bone. To achieve this ideal situation, an osteoplasty is generally performed with drills and/or pinza gubia (Fig. 5a, b).

Implant Placement

Normally the distribution of the implants is at the position of the canines (or lateral incisors), first premolars, and first molars. The implant sites are prepared with the help of the surgical guide (Fig. 6). The anterior implants are placed first. Those corresponding to the premolars are planned considering the distance to the mental foramina. Their angulation and position is checked with paralleling pins (Fig. 7) before inserting the implants (Fig. 8).

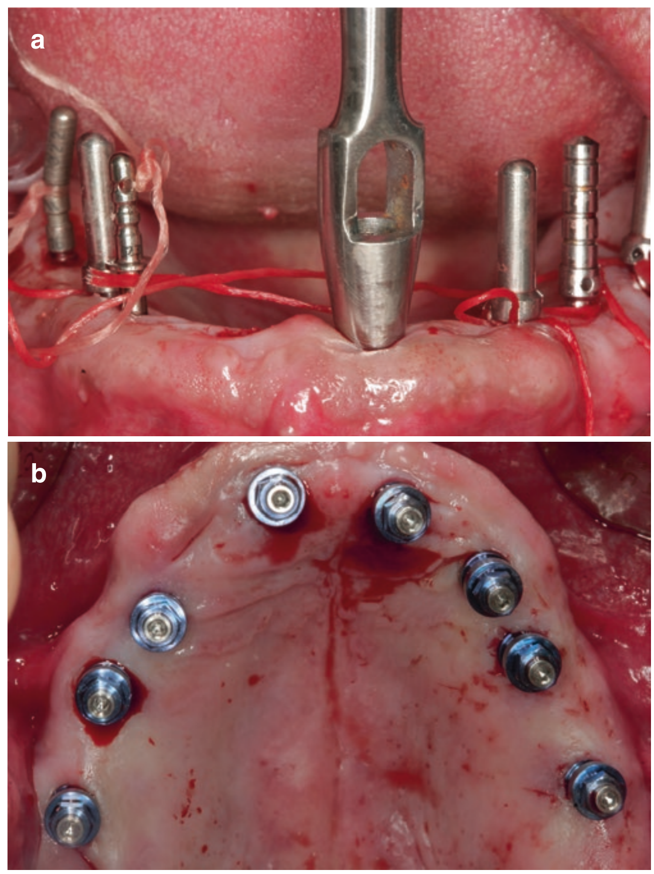


Fig. 3 Case carries out flapless surgery. (**a**) The gingiva is cutted with punch scalpel. (**b**) Implants (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain) placed through perforations of soft tissue

If the posterior bone is available, distal implants can be placed, irrespectively if they will be immediately loaded or not. The insertion and positioning of the anterior implants will serve as a guide for the insertion of the posterior implants (Fig. 9). If the posterior bone is not available due to alveolar atrophy, four implants are placed in the interforaminal

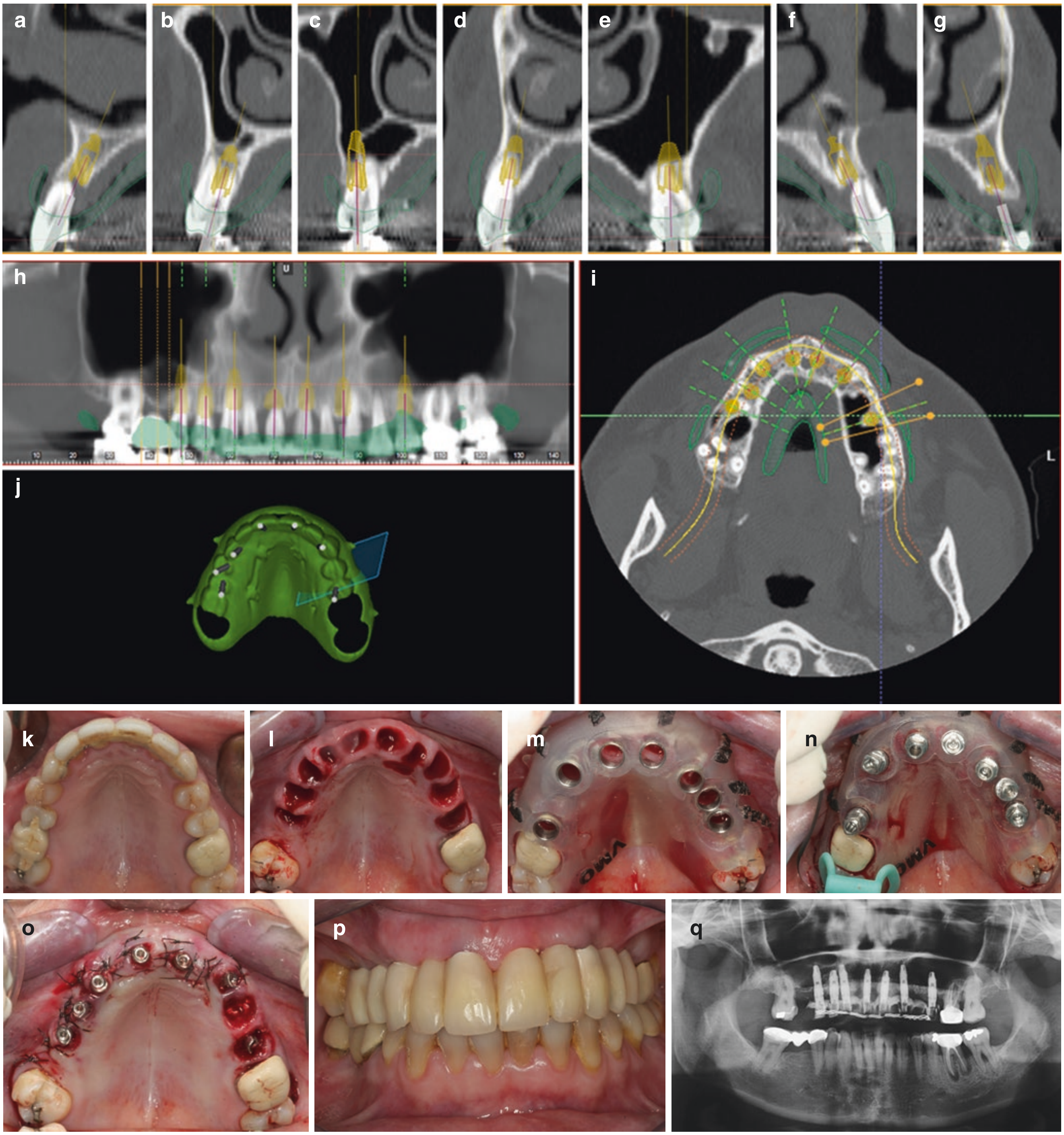


Fig. 4 CBCT slices for presurgical digital planning of the case. (**a**–**g**) Coronal and sagittal slices to evaluate vestibule-palatine implant position. (**h**) Orthopantomography reconstruction from CBCT. (**i**) Axial slices with implant position planning. (**j**) 3D creation of the surgical splint. Clinical images from the same case which made the 3D virtual planning. (**k**) Intraoral preoperative view. (**l**) Atraumatic extractions of the teeth. (**m**) Placement of the guided surgery splint stabilized by the molars and palate. (**n**) Insertion of the implants Galimplant® IPX (Galimplant Dental Implant System, Sarria-Lugo, Galicia Spain) guided by the splint. (**o**) Occlusal view after implant placement and suture of the soft tissue. (**p**) Provisional prosthesis. (**q**) Panoramic radiograph after placement of the prosthesis

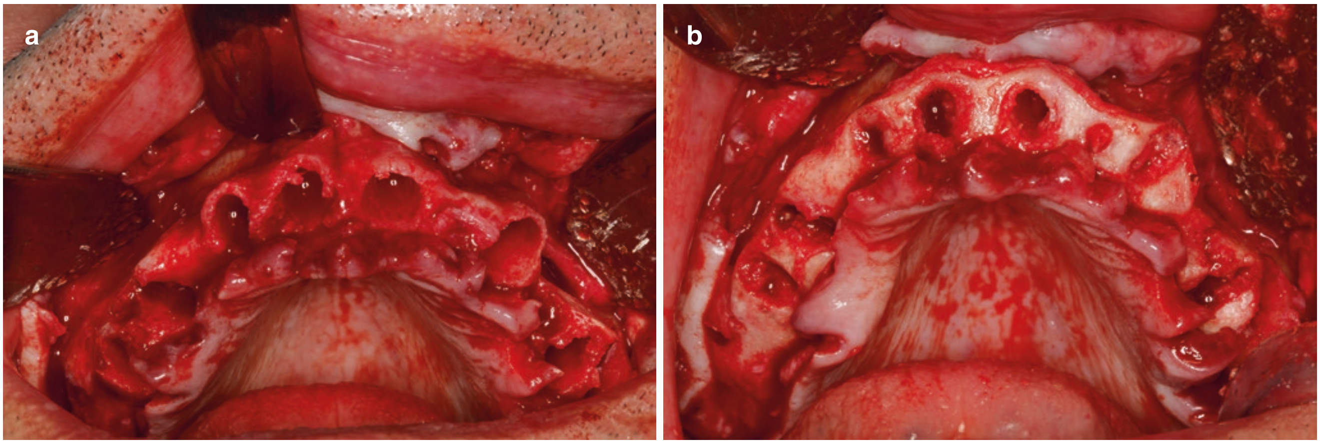


Fig. 5 Osteoplasty is done in a maxillary case after the extractions. (**a**) Shows post-extraction. Situation with an irregular alveolar process. (**b**) The alveolar process is regularized with osteoplasty before placing the implants

Fig. 6 The implant sites are prepared with the assistance of a surgical splint to facilitate a correct position and distribution

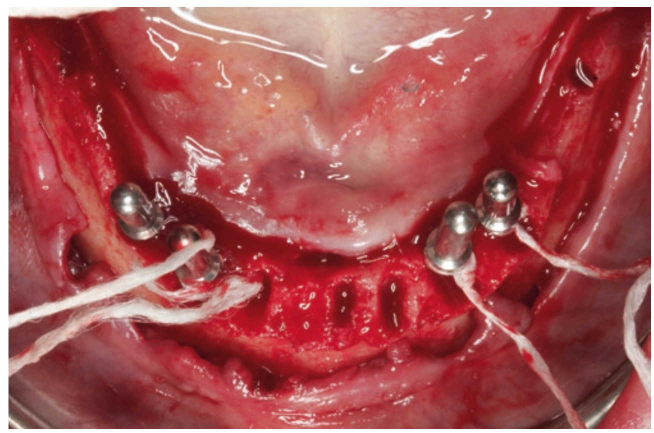


Fig. 7 The position and the angulation of the implant sites are checked with paralleling pins

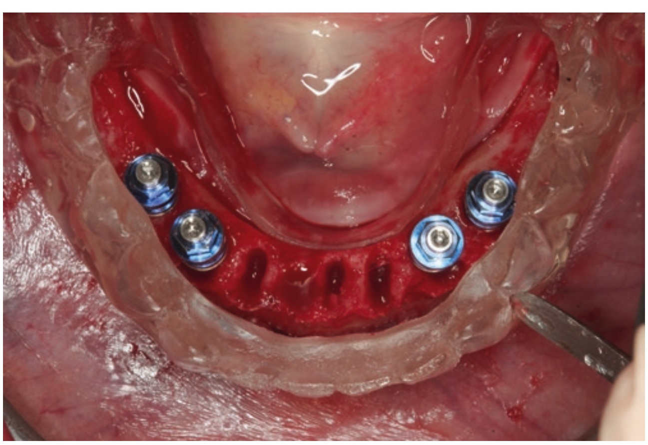


Fig. 8 The correct position of the anterior implants (Phibo TSA®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain) can be verified with the surgical splint

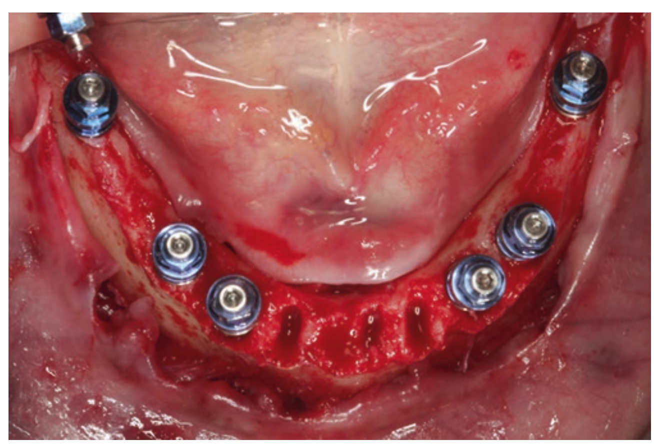


Fig. 9 The distal implants are placed using the anterior implants as reference

region, and a fixed temporary rehabilitation is made by means of an acrylic prosthesis with eight teeth (from the first premolar to second premolar). The definitive prosthesis can have up to ten crowns by means of a cantilever.

In case of performing extractions and placement of immediate implants, the two posterior implants can be positioned in the mesial root of the first molar, in the first premolar, and in the socket of the canine or lateral incisor on each side. The length and diameter of each implant can vary between patients depending on the quality and quantity of the bone in each site.

Methods to Enhance Primary Stability

Primary stability is evaluated by measuring the values of the insertion torque with a dynamometric ratchet or with the surgical motor. Additionally, resonance frequency analysis values can be obtained. It is generally accepted that implants should be inserted with a minimum torque force of 30 Ncm and have a minimum resonance frequency analysis value of 60 ISQ (Osstell ISQ®, Osstell AB, Göteborg, Sweden) (Fig. 10).

If bone quality is not optimum to obtain sufficient primary stability, several surgical methods have been described to achieve this:

- Undersized drilling technique

Underdrilling in sites with poor bone density (posterior edentulous maxilla and mandible) enhances primary implant stability (Turkyilmaz et al. 2008). The higher primary stability of implants inserted after undersized drilling compared with those inserted after standard drilling can be easily explained because the implants placed in undersized beds compress the bone and increase its density, thereby enhancing the primary implant stability (Alghamdi et al. 2011).

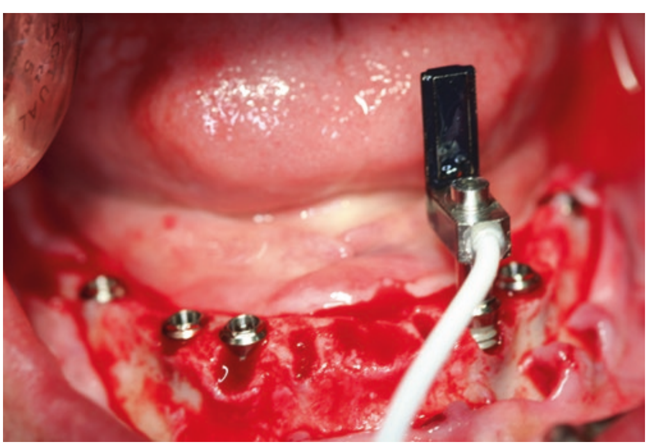


Fig. 10 The primary stability of the implants is checked with an Osstell® device

- Osteotome

Using osteotomes for implant site preparation allows to significantly increase primary stability through a similar process of increasing peri-implant bone density (Shayesteh et al. 2013; Marković et al. 2013) (Fig. 11). This increase in primary stability could be due to changes in the micromorphology of peri-implant trabecular bone caused by apicolateral condensation by osteotome (Javed and Romanos 2010).

- Bi-cortical anchorage

Cortical bone is much denser than cancellous bone, so placing implants with a double cortical anchorage allows achieving higher primary stability. All implants are anchored in the alveolar cortical, but additionally, double anchorage can sometimes be obtained in the sinus floor, pterygomaxillary bone mass, or even the nasal floor (Fig. 4a–c, e, g). The primary anchorage of the implant is, thus, improved thanks to increased bone to implant contact (Martinez et al. 2001).

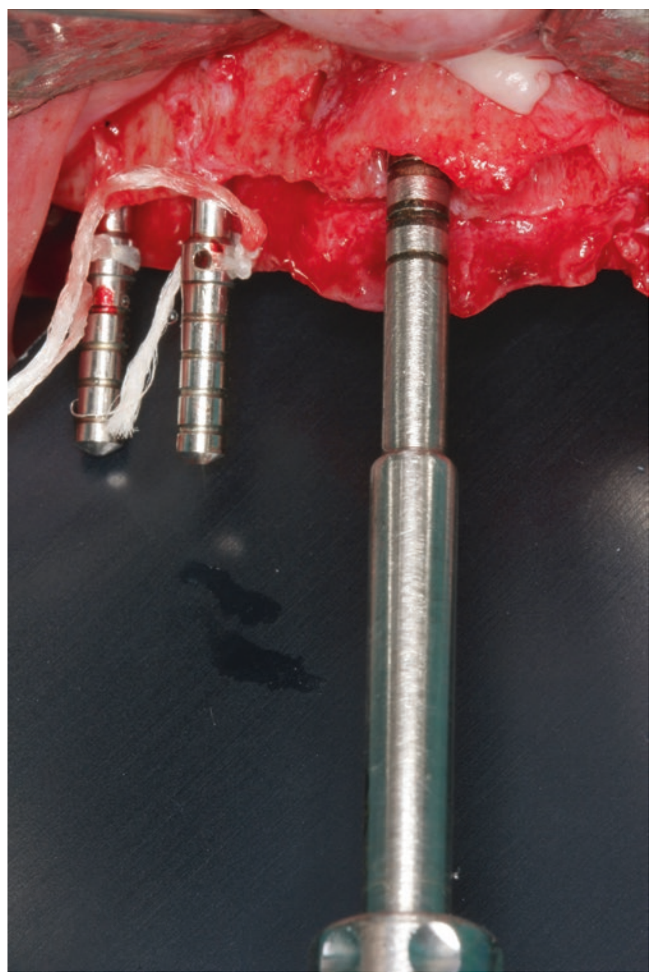


Fig. 11 Using osteotome for implant insertion is beneficial to increase the primary stability

Chairside Prosthetic Protocol (Direct Technique)

After implant placement (Fig. 12), the transmucosal abutments are selected according to the thickness of the soft tissues and screwed with a torque approximately 25 Ncm.

Once the corresponding transmucosal abutments have been fixed, provisional plastic or metal copings are screwed on the abutments manually. Their adaptation to the shoulder of the implant is checked, the incision is sutured (Fig. 13), and the mucosa is isolated with a rubber dam (Fig. 14).

The resin prosthesis is perforated (Fig. 15) and taken to the mouth to check its seating (Fig. 16). If there are interferences with the copings, the orifices are enlarged to create enough space to ensure the perfect seating of the prosthesis on the supporting tissues.

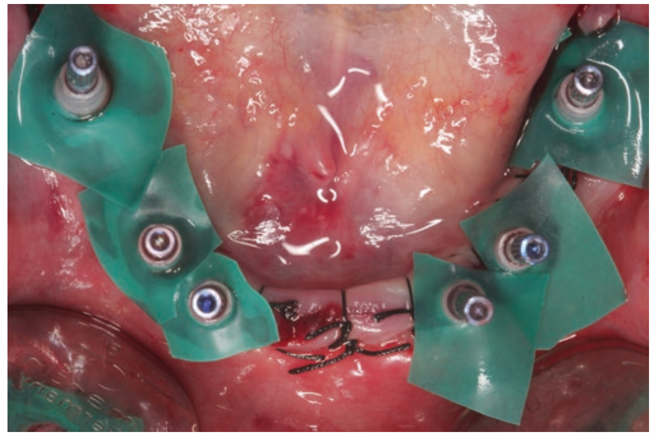


Fig. 14 Pieces of rubber dam are used to protect the surgical area

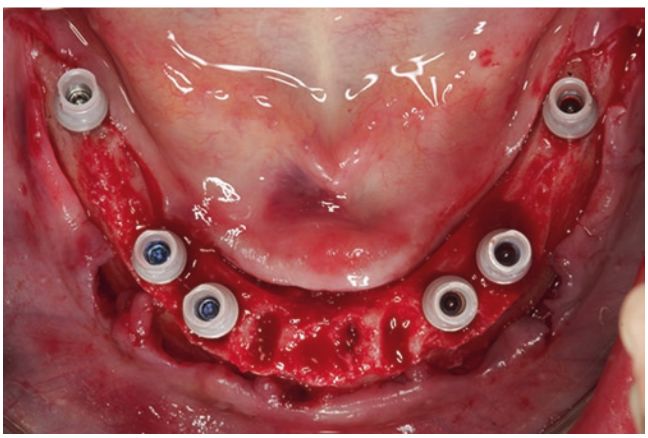


Fig. 12 Six implants inserted in jaw

Fig. 15 Perforations are made in the provisional prosthesis

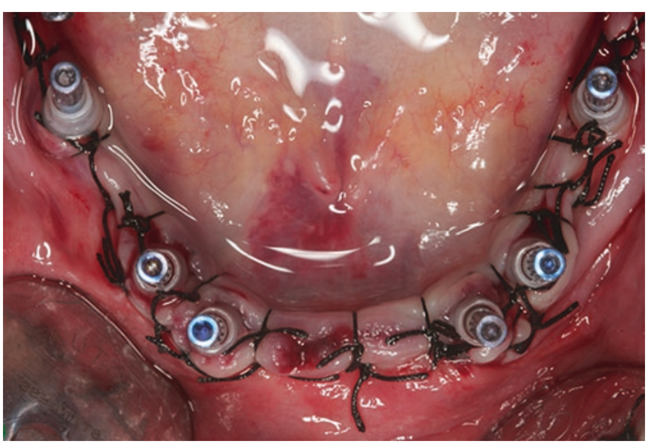


Fig. 13 The flap is sutured. Plastic copings are now fixed with long screws

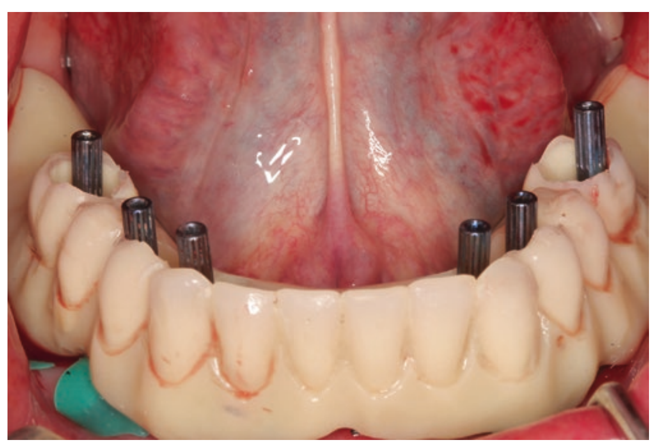


Fig. 16 The setting of the prosthesis is checked

At this moment, it is recommended to obtain a silicone or wax bite that will help maintain the correct position of the denture. The prosthesis is repositioned with only two long anterior laboratory screws in the most anterior implants and the silicon or wax bite (Fig. 17). The laboratory screws should not interfere with occlusion. If they interfere with occlusion, they will be cut in the occlusal part and a notch will be made to remove them with a screwdriver, or the bite can be made thicker.

The rebase of the denture will be carried out in two phases. First, the copings of the two central implants will be overlaid with resin, in order to have a first point of stability. Resin is added through the anterior perforations of the provisional denture (Fig. 18), while the bite wax is held in the right position as the patient is asked to close the mouth in the pre-established occlusion (Fig. 19).

After the setting of the resin of the two anterior implants, the bites are removed. The prosthesis is anchored in the mouth by the anterior implants. The long laboratory screws are placed in the four posterior implants, and the rest of the perforations are filled with acrylic resin (Fig. 20).

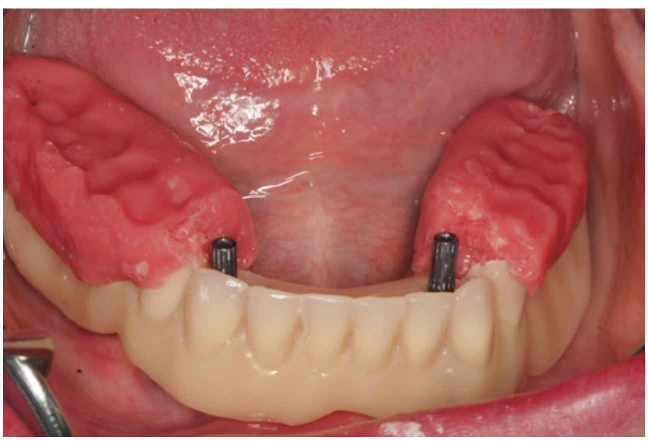


Fig. 17 The two anterior screws and the bite are placed

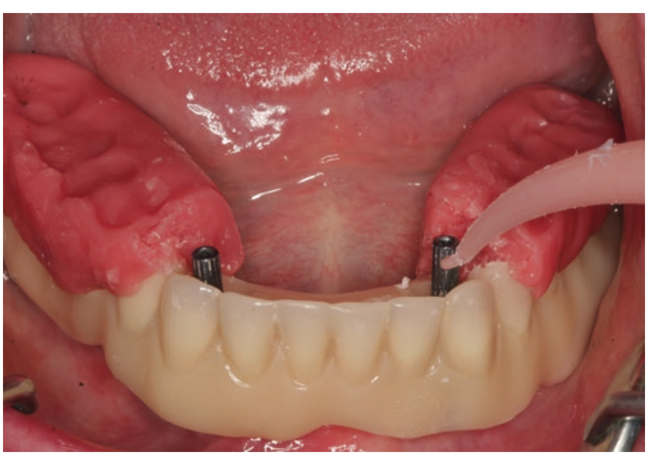


Fig. 18 Resin is introduced in the anterior perforations

Fig. 19 Polymerization of the resin with the denture held in position with the wax bites

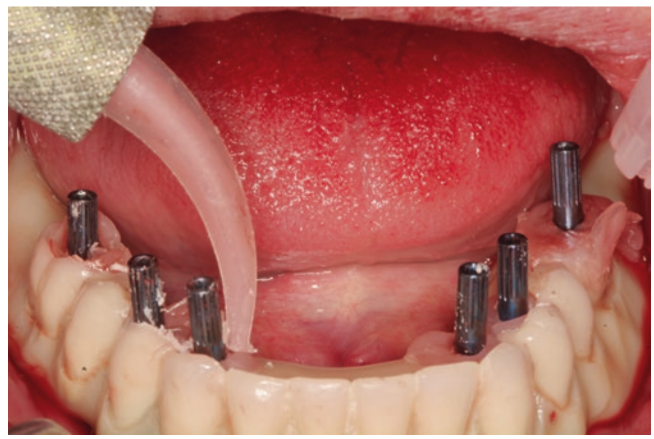


Fig. 20 Resin is introduced in the rest of the perforations to splint the posterior implants

Once all the resin is set, the provisional resin prosthesis is removed (Figs. 21 and 22). In the laboratory, additional resin is added where necessary, and resin excesses, cantilevers, and buccal/palatal flanges are removed to provide the provisional immediate loading prosthesis with a cleansable design. Thereafter, final polishing is carried out (Figs. 23 and 24).

The provisional prosthesis is taken to the mouth and screwed considering the torque recommended by the manufacturer for provisional abutments (approximately 15–20 Ncm) (Fig. 25). Access holes to the screw heads in the prosthesis are filled with Teflon and covered with a temporary filling material (Fig. 26).

The adjustment of the short screws is checked with a panoramic radiograph (Fig. 27). The occlusion is evaluated and corrected so that contacts are evenly distributed across the

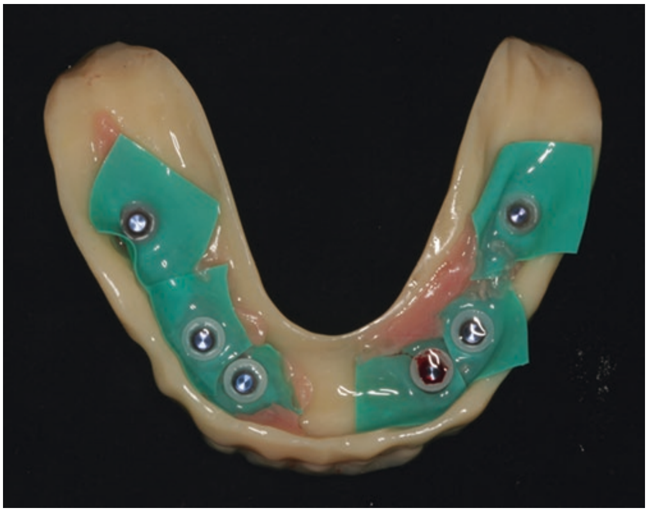


Fig. 21 The prosthesis is removed, with the rubber dams adhered

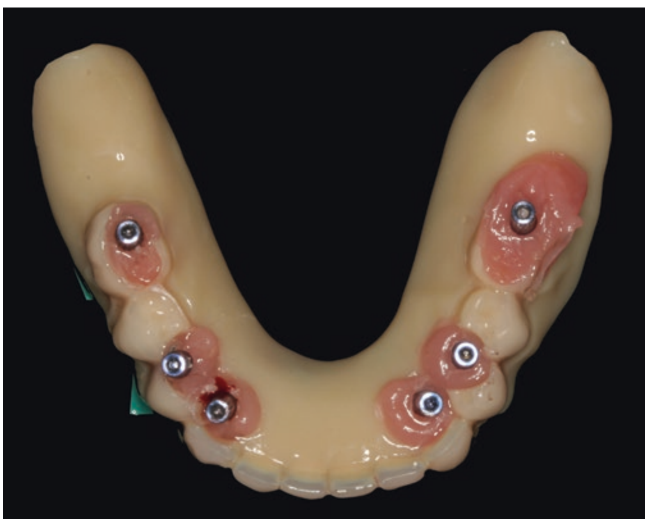


Fig. 22 Occlusal view of the provisional resin prosthesis

Fig. 23 The flanges of the prosthesis are removed, cantilevers are eliminated, and the excesses are polished

Fig. 24 Occlusal view of the provisional resin prosthesis after polishing

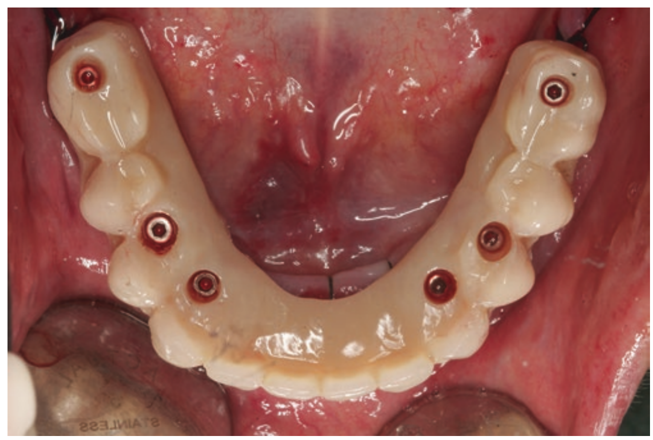


Fig. 25 The prosthesis is placed in the mouth and the short clinical screws are tightened to 15 Ncm

Fig. 26 The access holes to the screws are filled with temporary material

full-arch prosthesis and that there are no premature contacts or interferences (Fig. 28).

After the placement of the provisional prosthesis, patients are recommended to maintain a soft diet for 2 months and oral hygiene with the aid of irrigators. One week after the surgery, the provisional prosthesis is removed if necessary to remove the sutures. Thereafter the prosthesis will not be removed during the following 2 months.

After 3 months of placing the implants and the immediate temporary prosthesis, the process of preparation and placement of the definitive prosthesis is started, according to the standard prosthodontic procedure. The healing of the hard and soft tissue is completed (Fig. 29), and the definitive prosthesis is placed in the mouth of the patient (Figs. 30 and 31). A panoramic radiograph will allow to evaluate the implant-prosthesis adjustment (Fig. 32). In Table 1 the summary of the procedure is included.

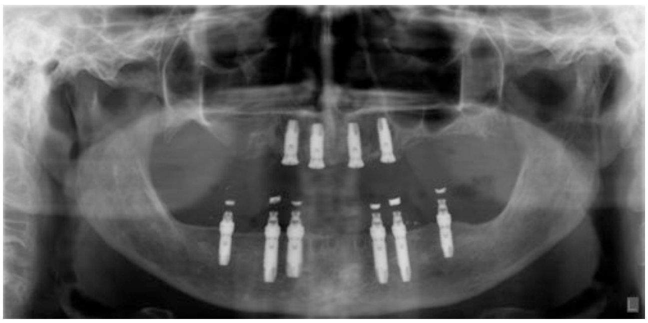


Fig. 27 Panoramic radiograph with the mandibular provisional resin prosthesis placed

Fig. 28 The occlusion is checked and adjusted

Fig. 29 Healing of the soft tissues after 3 months

Fig. 30 Definitive metal-ceramic prosthesis

Fig. 31 Definitive prosthesis placed in the mouth

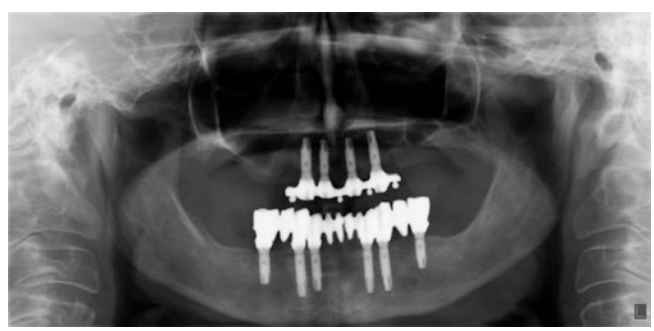


Fig. 32 Panoramic radiograph to evaluate the implant-prosthesis adjustment. The implant system was Phibo TSA® (Barcelona, Spain)

Laboratory Prosthetic Protocol (Indirect Technique)

In the indirect prosthetic protocol, the immediate loading full-arch prosthesis is fabricated in the laboratory, with the advantage that it can be reinforced with metal. The disadvantage of this technique is that it generally involves a delay for prosthesis delivery of several days, as it takes 24 to 72 h for the laboratory to fabricate the prosthesis. One case is exposed as an example (Fig. 33a, b).

A first conventional impression is made preoperatively. We should request to the laboratory a transparent resin surgical splint, a provisional removable complete denture, and another splint to register the implants' positions intraoperatively. This last splint has no buccal flange, and it is supported and stabilized by the posterior areas of the alveolar process and a couple of anterior remaining teeth that will be removed after placing the implants (Fig. 34). We must verify before the surgery that the surgical splint and the impression splint are stable.

All teeth can be extracted except those on which the impression splint is supported (Fig. 35). The implants are then placed with the help of the surgical splint (Fig. 36). Thereafter, the implants' position is registered intraoperatively. To do this, the impression transfers are placed and the mucosa is protected with rubber dam (Fig. 37). The impression splint is placed in the mouth in its stable position and the implant transfers are fixed to it with DuraLay® resin (Dental Mfg. Co., Worth, Illinois, USA) (Fig. 38).

Once the DuraLay® resin has set, the impression splint and implant impression transfers are removed from the patient's mouth (Figs. 39 and 40a, b). The remaining teeth are then extracted, and finally, healing abutments are placed and the soft tissues are sutured (Fig. 41). If it is possible, it is useful to suture at a distance from the incision line to facilitate suture removal without the need to disassemble the immediate loading prosthesis. A conventional removable denture can be adjusted so that the patient can use it until the laboratory fabricates the immediate loading fixed prosthesis (Fig. 42).

Table 1 Chairside protocol for fixed full-arch immediate loading (direct technique)

1	Diagnostic impressions, facial arch, articulator mounting, and diagnostic wax-up
2	Preparation of a surgical guide and a provisional resin prosthesis
3	Bite in the articulator
4	Eventual extraction of the remaining teeth.
5	Ostectomy to regularize the bone crest
6	Placement of four to eight implants
7	Placement of transmucosal abutments and temporary metal/plastic copings
8	Suture
9	Rubber dum to protect the surgical wound
10	Verification of the fit of the provisional prosthesis
11	Placement of the bite
12	Splinting of the provisional prosthesis and the copings with self-curing resin through the perforations and setting in occlusion
13	Adaptation in the laboratory, removing resin excesses, cantilevers, and flanges
14	Polishing of the prosthesis
15	Placement of the provisional screwed prosthesis
17	Checking the radiographic adjustment
18	Filling occlusal perforations with temporary cement

Fig. 34 Transparent resin splint that is supported on canines, palate, and retromolar area that will be used to register implant positions

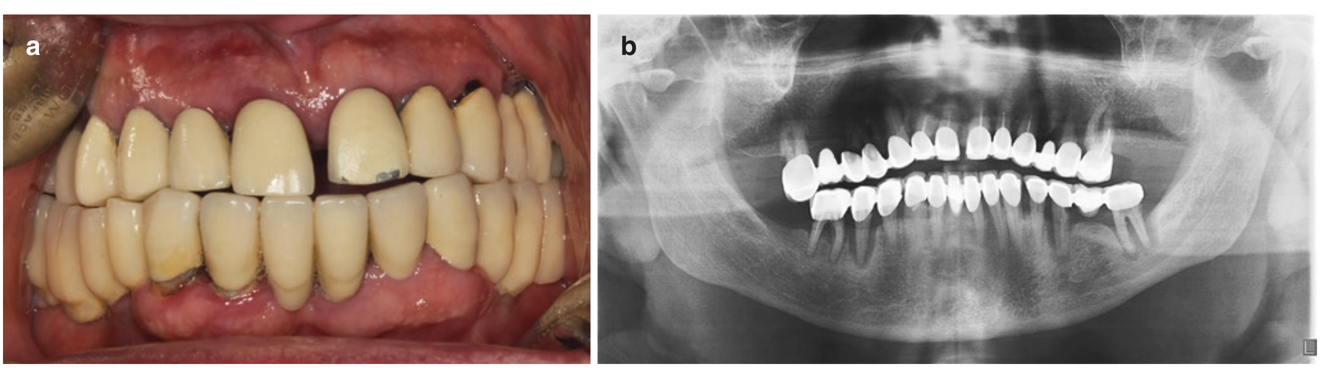


Fig. 33 Initial situation of the patient. (**a**) Frontal intraoral picture. (**b**) Panoramic radiograph of the initial situation

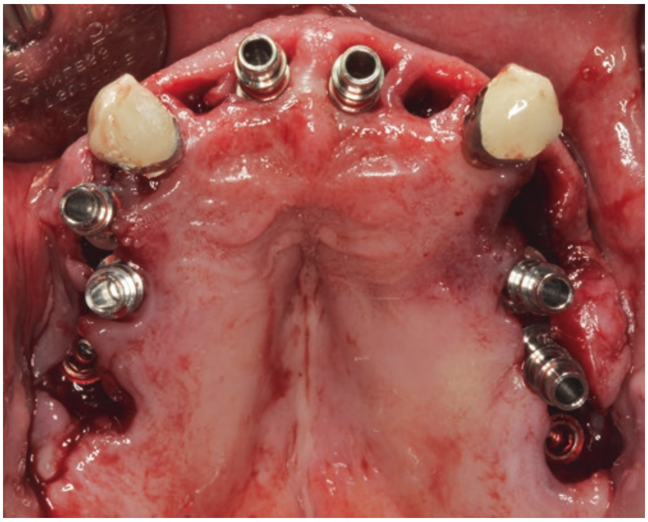


Fig. 35 Implants Phibo TSA® placed after removal of the splint

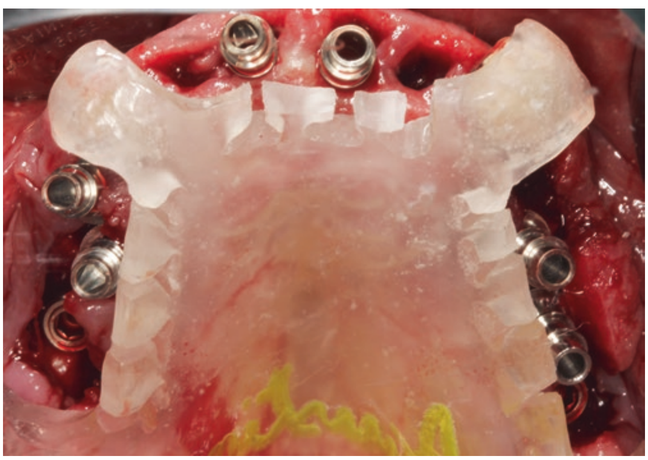


Fig. 36 Implants placed. The canines have not yet been extracted

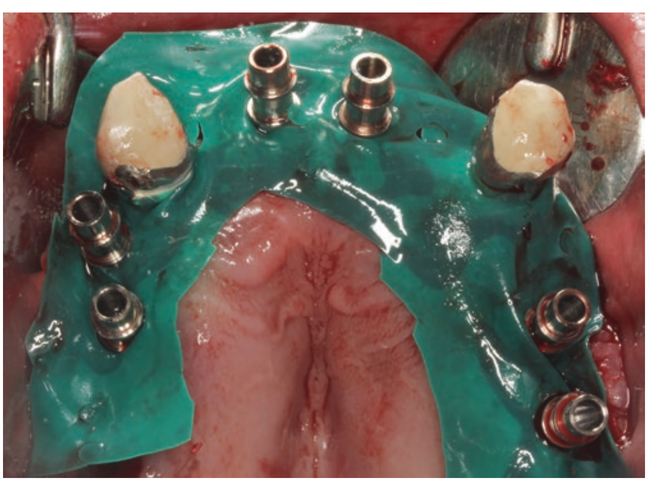


Fig. 37 Insertion of the impressions transfers and placement of the rubber dam to protect the surgical field

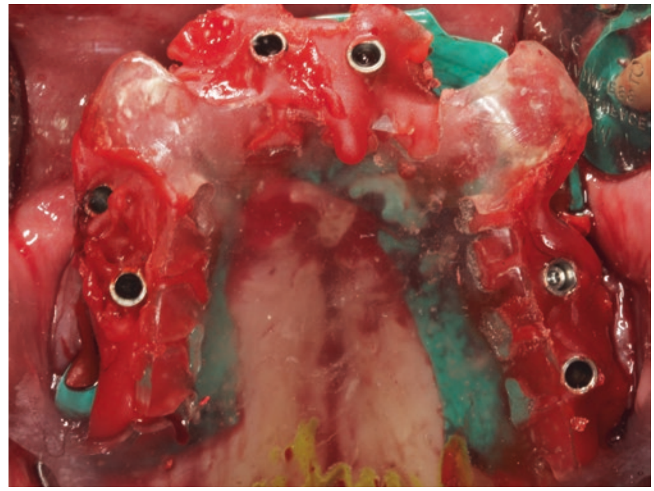


Fig. 38 Placement of the impression splint and splinting of the transfers to the splint with Duralay® resin

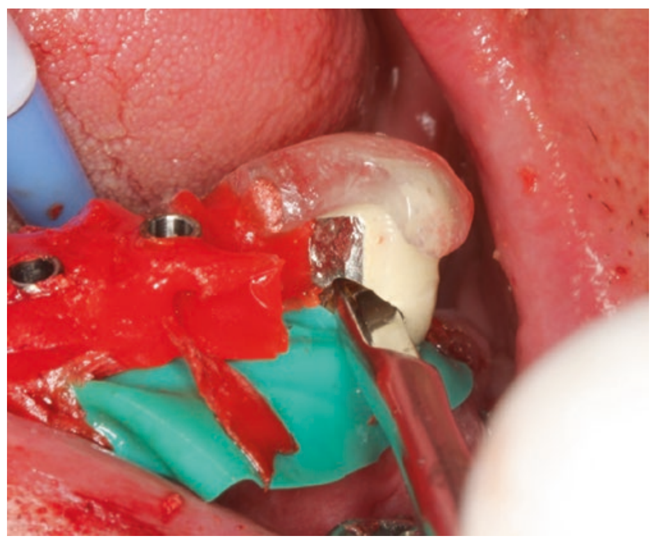


Fig. 39 Once the resin is set, the coronectomy of the canines is performed to remove the splint

To fabricate the immediate loading prosthesis, the dental technician uses the impression splint to position the implant replicas in the diagnostic model. First, the technician assembles the articulator (Fig. 43), and he eliminates the teeth except those necessary to stabilize the impression splint on the model (Fig. 44). Moreover, the technician eliminates plaster to make space to place the impression splint with the implant replicas screwed to the transfers (Fig. 45). Once the impression splint is stable and in the right position on the model (Figs. 46 and 47), the technician uses plaster to fix the replicas in the diagnostic model in the registered positions (Figs. 48 and 49) and assembles the teeth test in the articulator (Fig. 50). The fixed temporary full-arch resin prosthesis is made with a cast metal reinforcement and without distal cantilevers (Figs. 51, 52, and 53a, b).

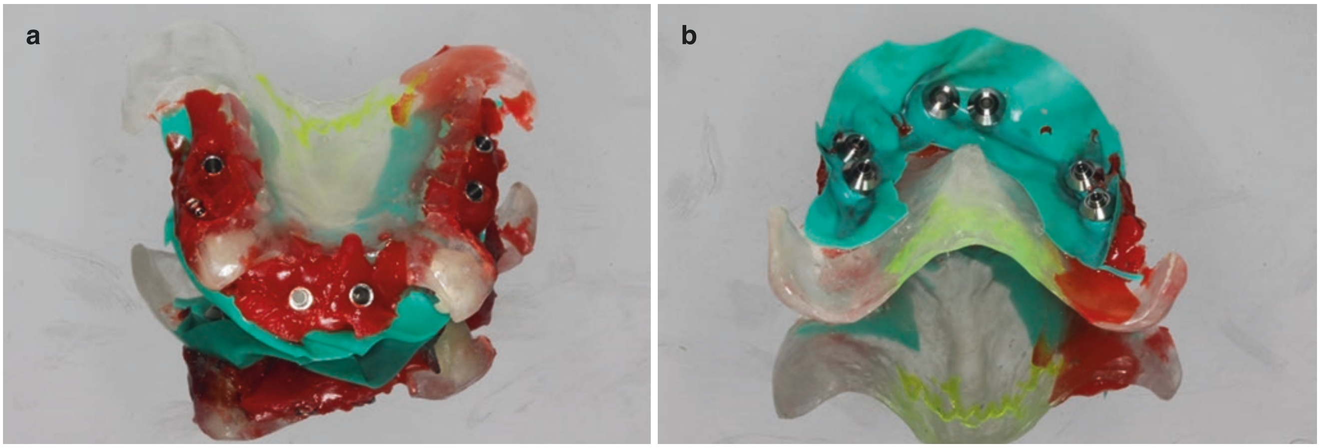


Fig. 40 Result of the registration of the implant positions: impression splint, implant transfers, rubber dam, and set resin. (**a**) Occlusal image. (**b**) Palatal image

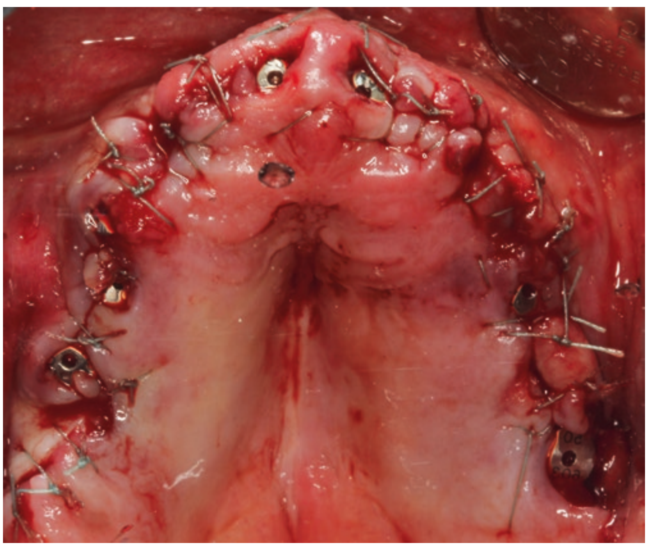


Fig. 41 Sutures at a distance from the incision line so that they can be removed without disassembling the prosthesis

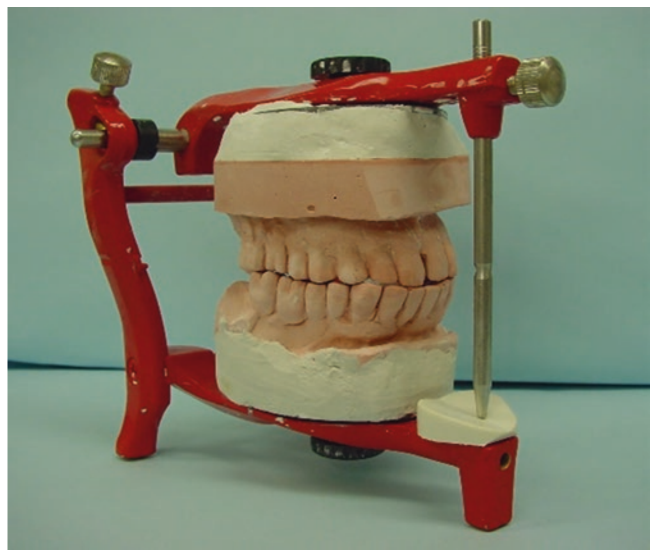


Fig. 43 Diagnostic model assembled on the articulator

Fig. 42 Temporary complete removable prosthesis delivered for esthetic purposes until the immediate loading prosthesis is fabricated

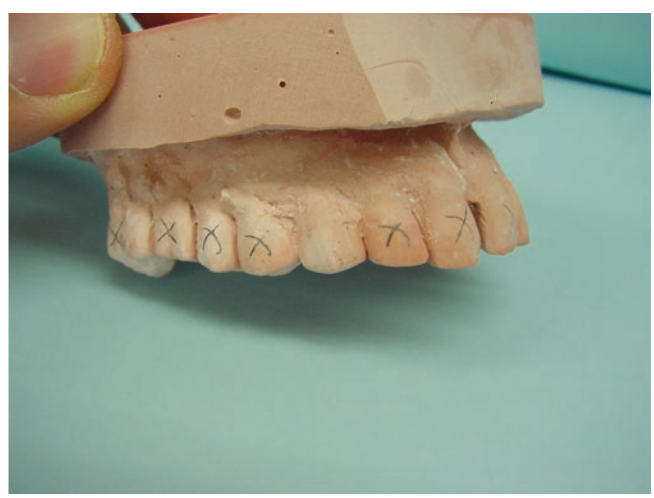


Fig. 44 Mark of the teeth that has to be removed from the diagnostic model at this stage

Fig. 45 The model is perforated so that it can accommodate the laboratory analogs

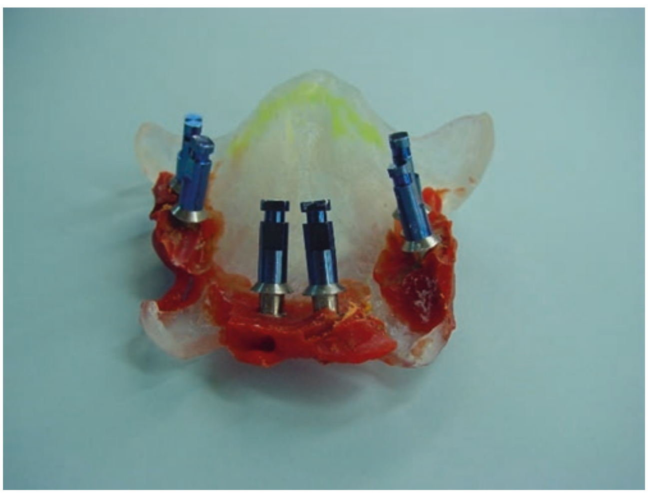


Fig. 46 Placement of implant laboratory analogs screwed to the transfers

Fig. 47 The impression is placed on the diagnostic model and its adjustment is checked

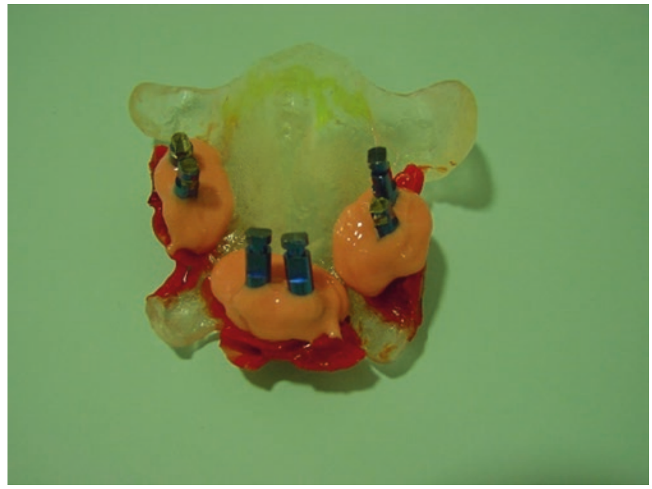


Fig. 48 Silicone to create the artificial gingiva in the plaster model

Fig. 49 Analogs placed in the model

Fig. 50 Assembly of teeth test in the articulator

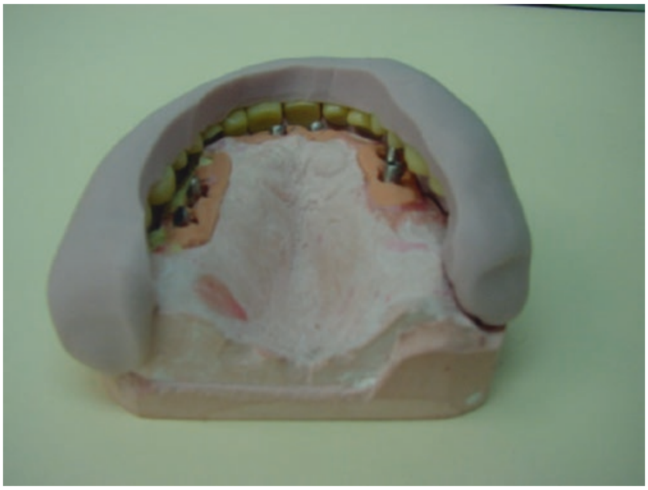


Fig. 51 Silicone key to transport the position of the teeth on the metal structure

This immediate loading prosthesis is placed up to 7 days after the surgery and screwed with a torque of 15–20 Ncm. It should not be removed for at least 8 weeks (Figs. 52, 53, 54, 55, and 56), when the fabrication of the definitive prosthesis can start.

Alternative Prosthetic Protocols

Flexafit® System

The fabrication of interim prostheses for immediate loading is a complex process. The Flexafit® (Dentisel®, Barcelona, Spain) technique introduces a system of abutments with a pressure or friction fitting to retain implant-supported prostheses.

Fig. 52 Cast metal structure

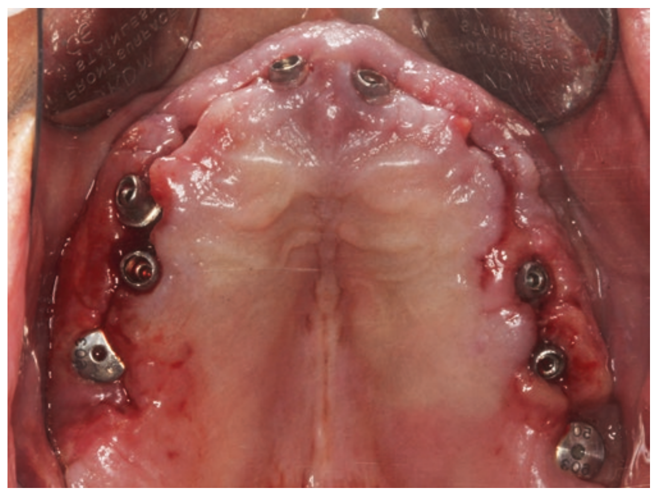


Fig. 54 Soft tissues 1 week after the surgery, after removing the suture

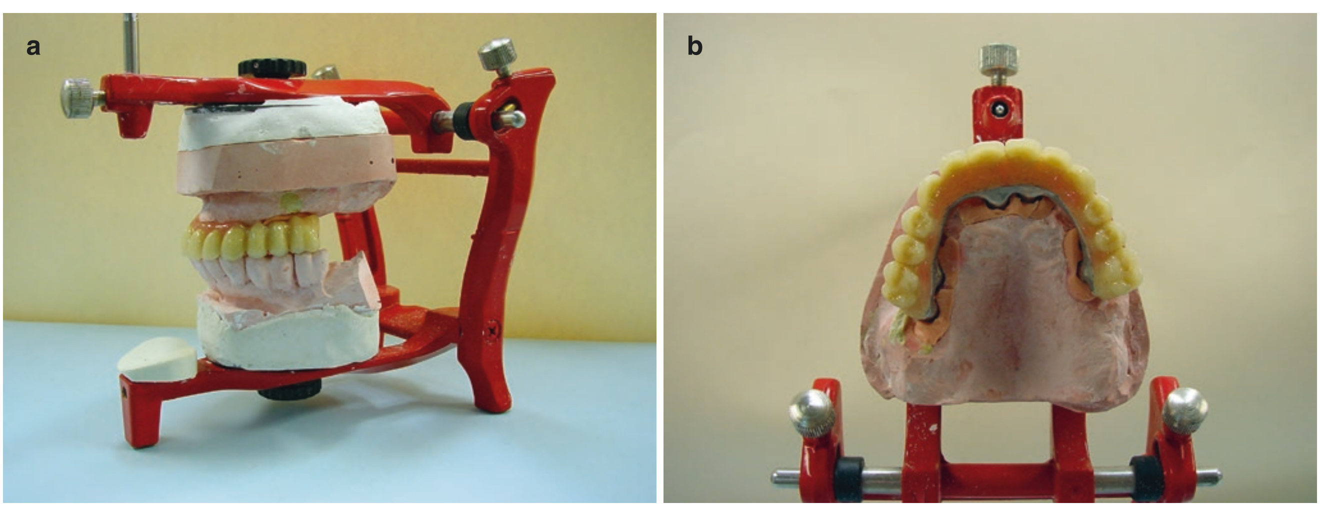


Fig. 53 Immediate resin prosthesis with metal reinforcement. (**a**) Lateral view in the articulator. (**b**) Occlusal view in the articulator

Fig. 55 Frontal view of the immediate loading provisional prosthesis

Fig. 56 Occlusal view of the immediate loading provisional prosthesis

The Flexafit® prosthetic abutment system offers advantages over traditional techniques for immediate loading interim prostheses. The system combines the main advantages of cement and screw-retained immediate loading prostheses, which are the easier achievement of passive fit easier retrievability, respectively. This system has a snap-on connection that can be used during the splinting, adjustment, and modeling phase of the immediate loading process and a screwed connection that can be used once the provisional prosthesis has been adapted on the implants (Fig. 57a, b).

Both, the abutments and the components are made of metal, unlike other snap-on systems which are made of plastic; this results in better connection precision and less micro-movements (Walker et al. 2007).

A clinical case using the Flexafit® system for immediate loading in the maxilla is presented to illustrate the steps of this technique (Fig. 58a–c):

1. The laboratory technician makes a diagnostic wax-up on the articulator. Next, a silicone key is made. This key is used to taken to facilitate filling with resin and holding the provisional prosthesis in the correct position (Fig. 59a–d).
2. Placement of the implants with adequate primary stability for immediate loading (Peñarrocha-Oltra et al. 2013) (Fig. 60).
3. The Flexafit® primary abutments are screwed with an insertion torque of 30 Ncm (Fig. 61).
4. Placement of thin protective plastic film over the Flexafit® primary abutments and their screws (Fig. 62).

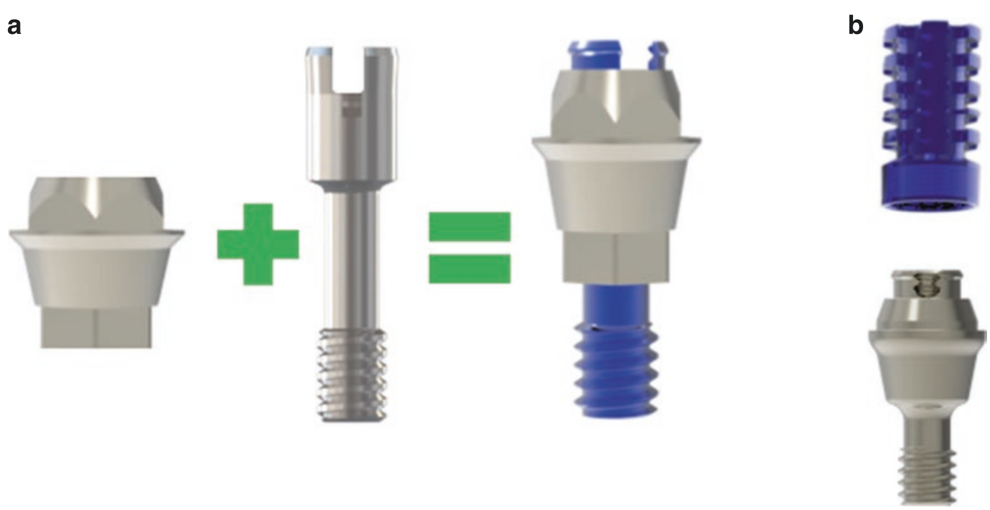


Fig. 57 Components of Flexafit® system: (**a**) Primary Flexafit® abutment and (**b**) secondary Flexafit® abutment together screwed.

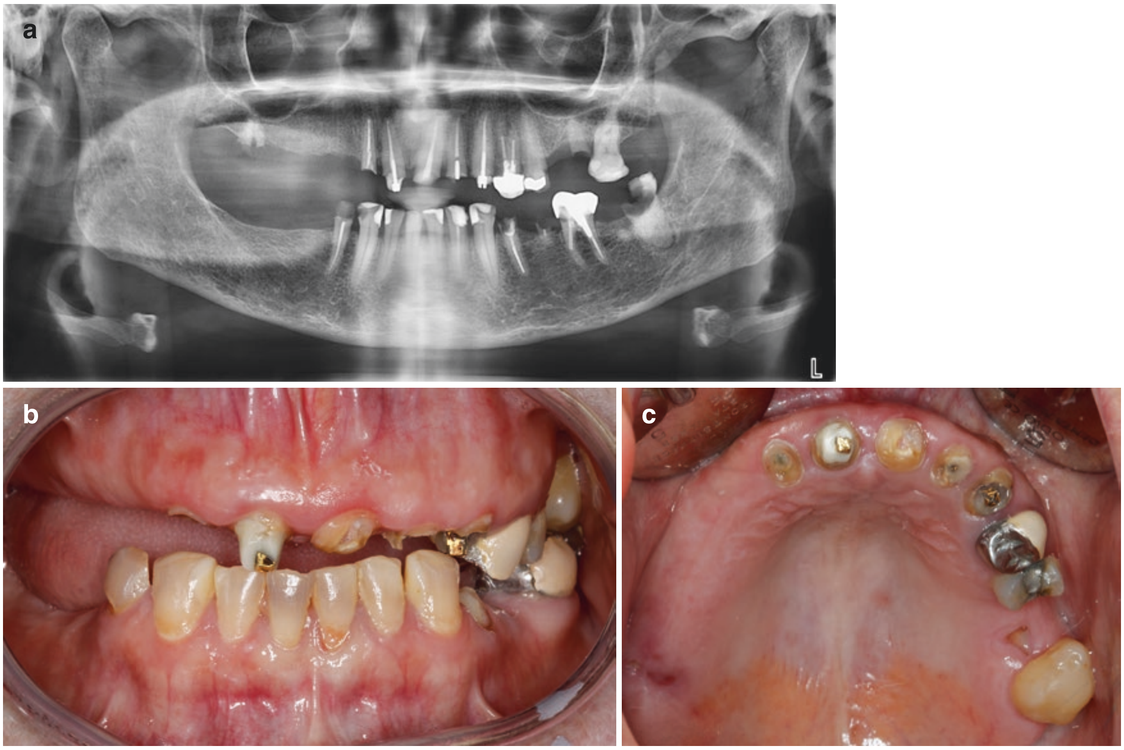


Fig. 58 Initial situation of a case planned for immediate loading in the maxilla using the Flexafit® system. (**a**) Extraoral panoramic radiograph. (**b**) Intraoral frontal view. (**c**) Occlusal view

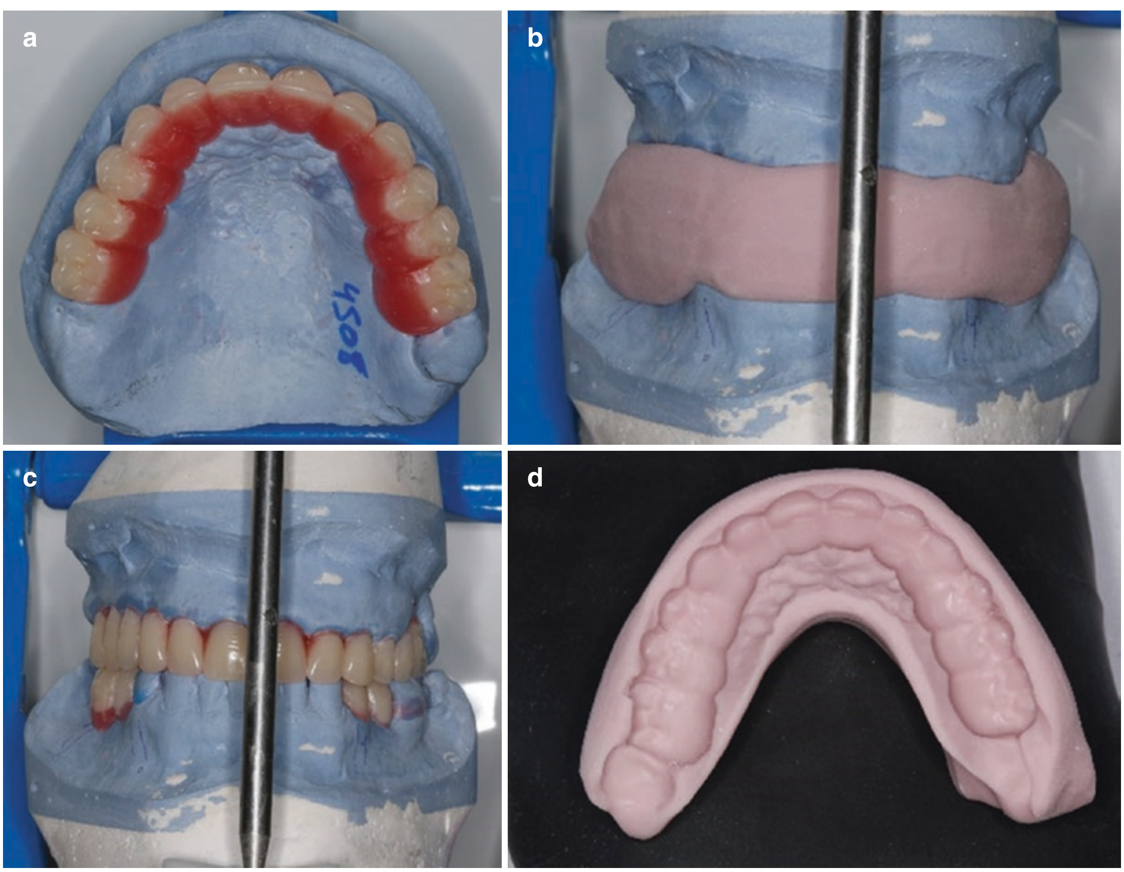


Fig. 59 Laboratory process: Fabrication of the wax-up in the articulator. (**a**) Occlusal view (**b**) Frontal view. (**c**, **d**) A silicone mold is taken to facilitate filling with resin and holding the provisional prosthesis in the correct position

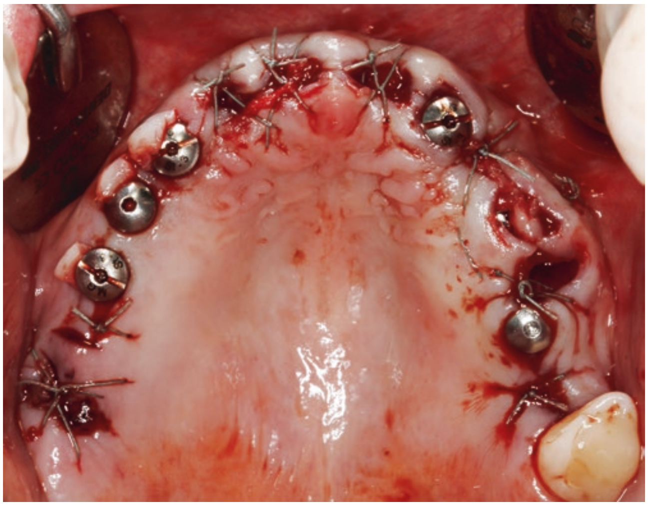


Fig. 60 Placement of the implants Phibo TSH® (Barcelona, Spain) with adequate primary stability for immediate load

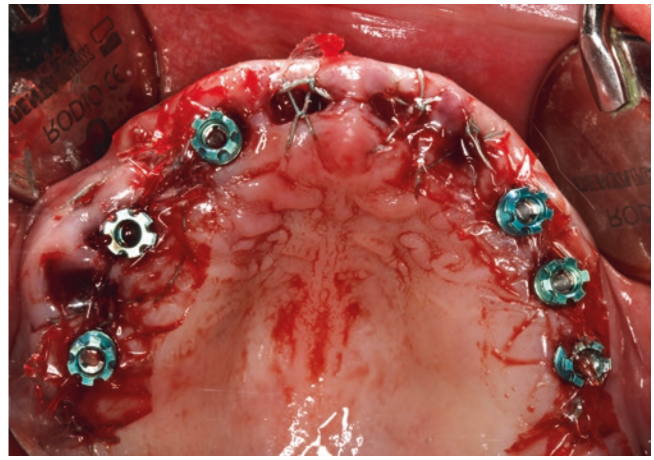


Fig. 62 The Flexafit® secondary abutments are screwed with an insertion torque of 30 Ncm, and a thin protective plastic film is placed over them

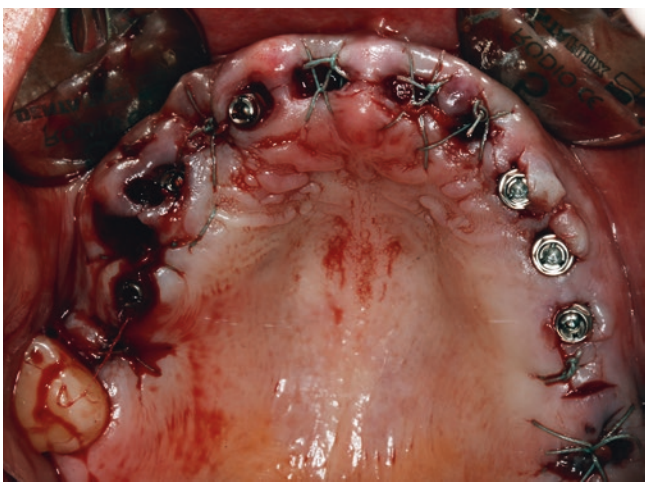


Fig. 61 The Flexafit® primary abutments are placed on each implant

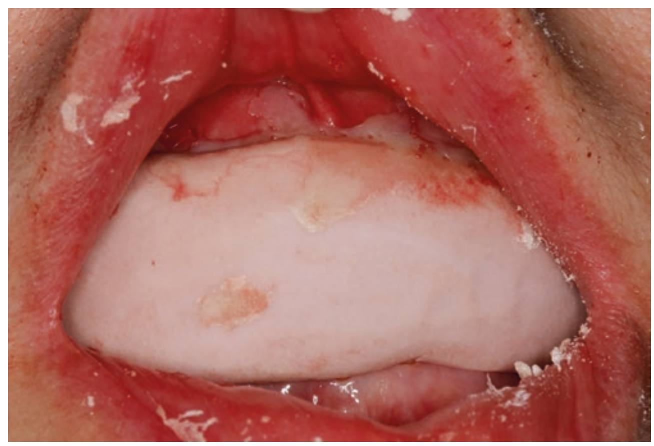


Fig. 63 The silicone mold is used to rebase the provisional prosthesis in the right position

5. Fitting with friction of the secondary abutments over the primary abutment with the protective plastic film positioned between the two abutments. The plastic film will prevent acrylic resin from penetrating the surgical area and the primary abutments (Fig. 62).
6. Block of the perforation of the secondary abutment through which the prosthetic fixation screw will be inserted with wax.
7. Rebase the interim prosthesis with acrylic resin (Reef Crown&Bridges®; Sweden&Martina, due Carrare, Italy), and place it in the mouth in the right position by means of silicone mold (Fig. 63). Once the resin has polymerized, the secondary abutments are embedded in the prosthesis.
8. Remove the interim prosthesis from the mouth by applying traction, and eliminate the protective film covering the primary abutment screw assemblies.
9. Adjust the interim prosthesis to obtain the correct emergence profile.
10. Connect in turn each secondary abutment to the Flexafit® drill (Fig. 64) to enable an easy and precise preparation of the screw access holes of the interim prosthesis. The Flexafit® drill has a platform identical to that of the primary abutment screw complex, so the secondary abutment fits on the Flexafit® drill by applying pressure.
11. Lower the 2-mm-diameter tungsten carbide drill over the prosthesis so that it creates the screw access hole

Fig. 64 Flexafit® drill: 2-mm-diameter tungsten carbide drill with which the screw access hole can be easily done with no risk of damaging the secondary abutment

without damaging the secondary abutment (Fig. 65). This is done for each secondary abutment.

12. Evaluate the insertion of the prosthetic fixation screws through the prepared perforations.
13. Polish the interim prosthesis (Fig. 66a, b).
14. Fit the interim prosthesis into the primary abutments. Then screw the prosthesis with the prosthetic fixation screws, applying an insertion torque of 15 Ncm (Fig. 67a, b).

The patient is evaluated at 2 months of the surgery, and the immediate prosthesis and soft tissues are correct and healthy, respectively (Fig. 68a, b).

PIC Camera®

Traditional impressions for complete-arch restorations are complex, time-consuming, and can be uncomfortable for the

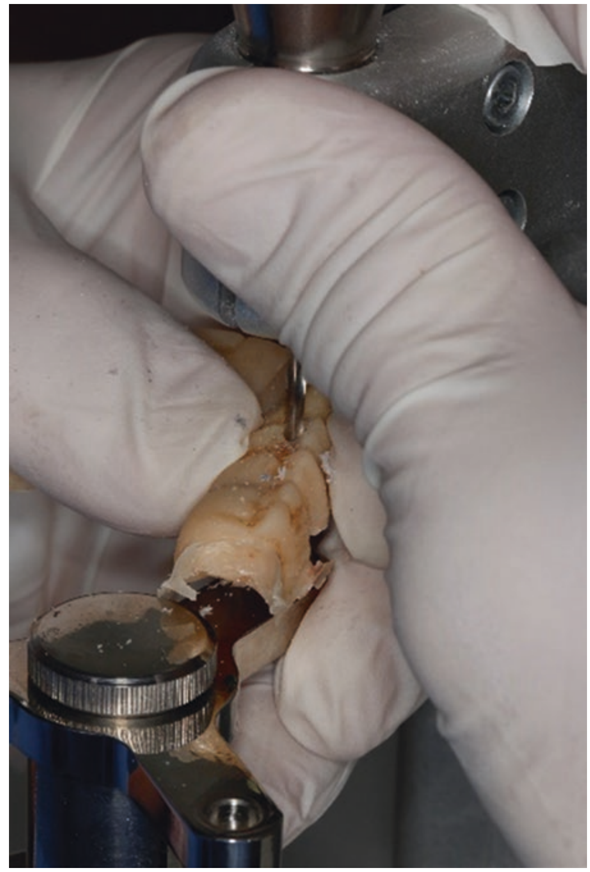


Fig. 65 The prosthesis can be fixed precisely on the Flexafit® drill as it has a platform identical to the Flexafit® primary abutment

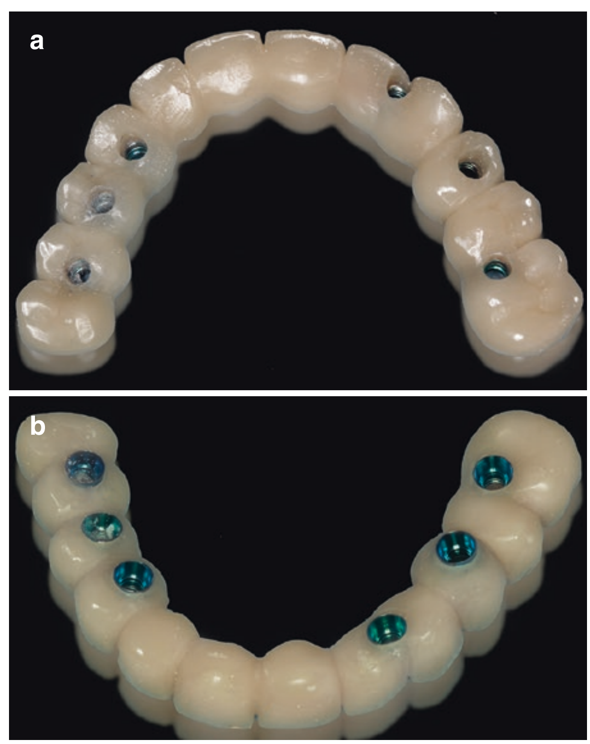


Fig. 66 Finished and polished provisional prosthesis. (**a**) Occlusal view (**b**) The secondary abutments are retained in resin

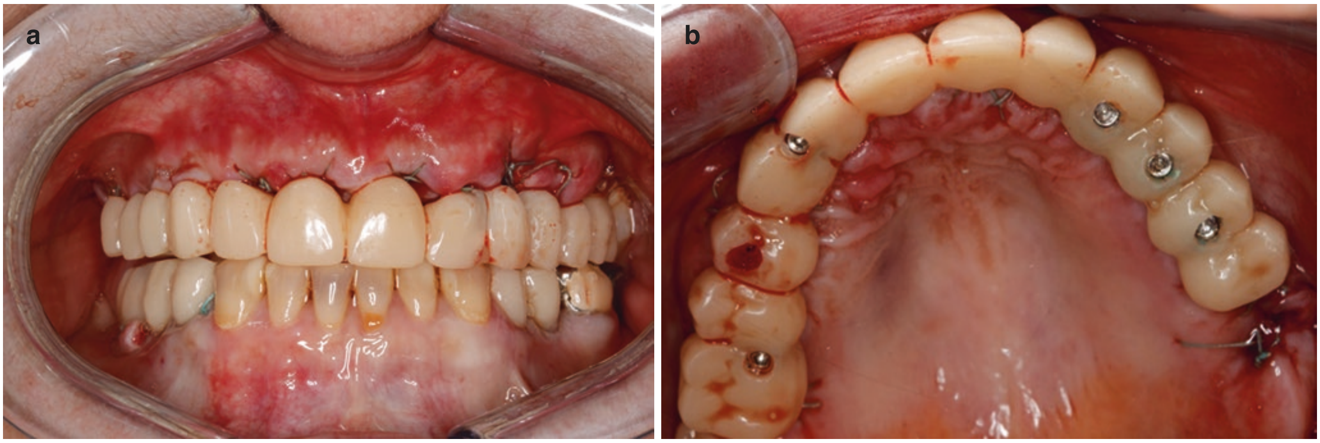


Fig. 67 Fit the provisional prosthesis into the primary abutments. Then screw the prosthesis with the prosthetic fixation screws, applying an insertion torque of 15 Ncm. Frontal (**a**) and occlusal view (**b**)

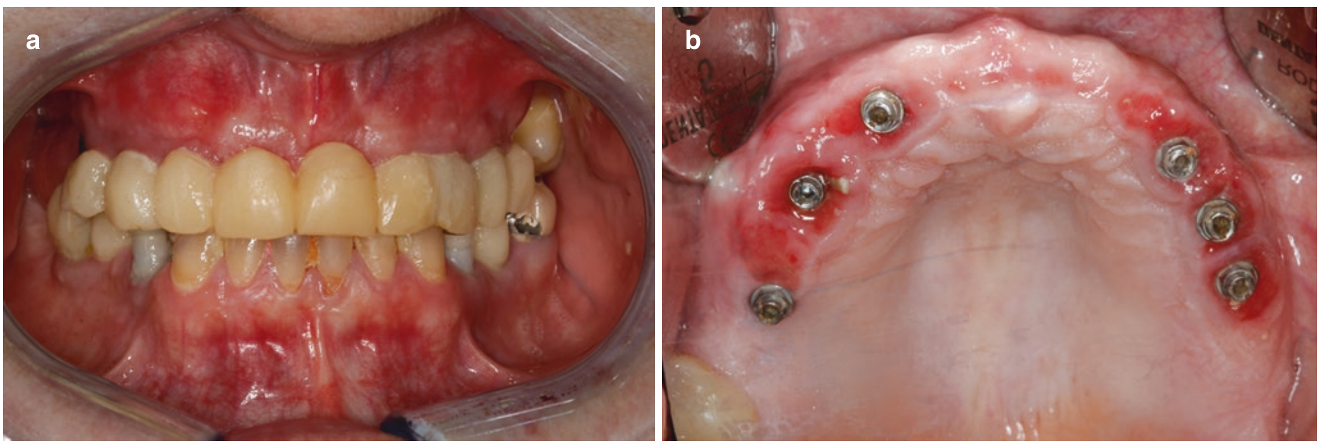


Fig. 68 Review at 2 months with (**a**) and without (**b**) the immediate loading prosthesis

Fig. 69 Initial panoramic radiograph

patient. New digital techniques such as stereophotogrammetry may mitigate this. Patient and dentist satisfaction improves, and the work time is reduced (Agustín-Panadero et al. 2015). A clinical case is exposed to understand the procedure by PIC Camera® (PicDental®, Madrid, Spain) (Figs. 69 and 70a–c) with 3D planning (Fig. 71). This case was operated by a flapless surgery (Fig. 72a–d).

After implant placement, the healing abutments are screwed and their height is recorded. The soft tissues are registered either with a conventional impression that is poured with gypsum and digitalized with a laboratory scanner or directly with an intraoral scanner. Then the scanbodies (PIC abutment; PIC Dental) are screwed into the implants (Fig. 73). The PIC Camera® consists of two infrared charge-coupled device (CCD) cameras that register the distance and angulation between the scanbodies using photogrammetry. The cameras register 50 images for every two abutments. Thus, for an edentulous case, it obtains 600 images in under 60 s.

The file with the position of the implants registered with the PIC Camera® is automatically aligned with the soft tissues file by best fit. In order to establish the vertical dimension and perform a trial tooth arrangement, a virtual articulator or a physical definitive cast is required. A 3D printer (Objet Eden 260VS; Stratasys) can be used for this second option. Once the vertical dimension is established, the metal framework of the prosthesis is designed, filed in open 3D stereo-

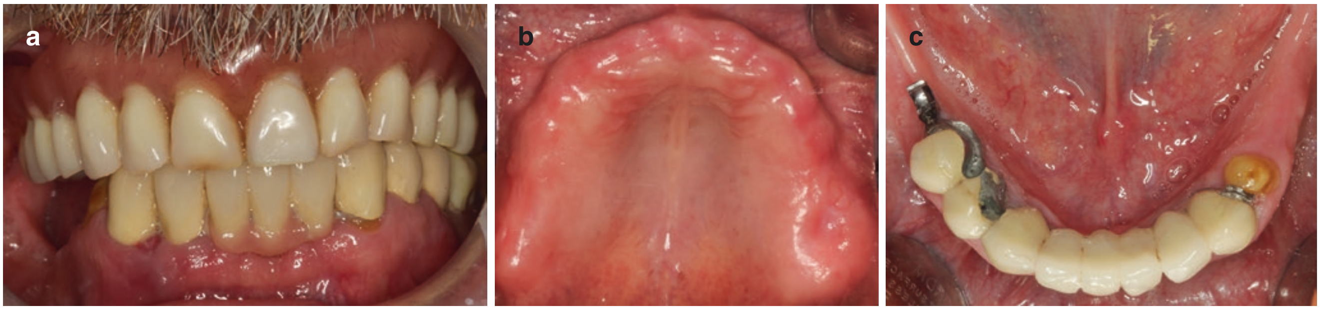
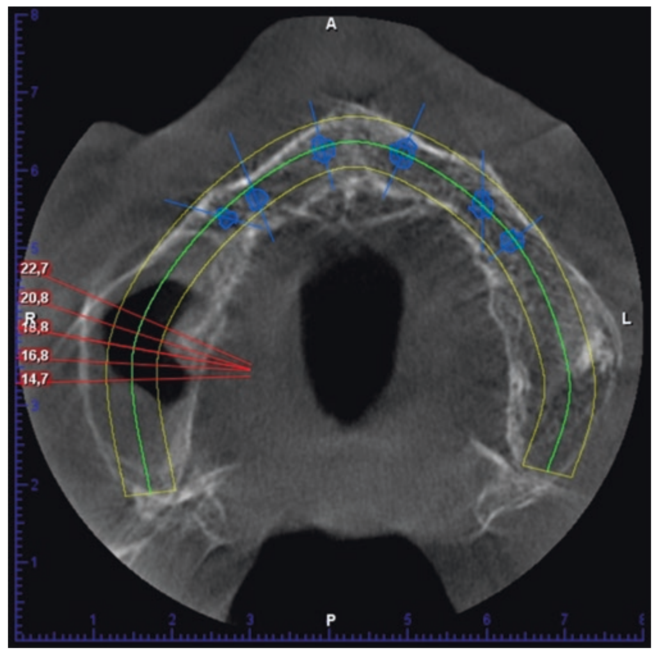


Fig. 70 Intraoral views: (**a**) frontal with the patient's conventional prosthesis, (**b**) occlusal view of the edentulous maxilla, and (**c**) occlusal view of the remaining mandibular teeth

Fig. 71 3D planning of the implant surgery; axial slices with the planning of the implants



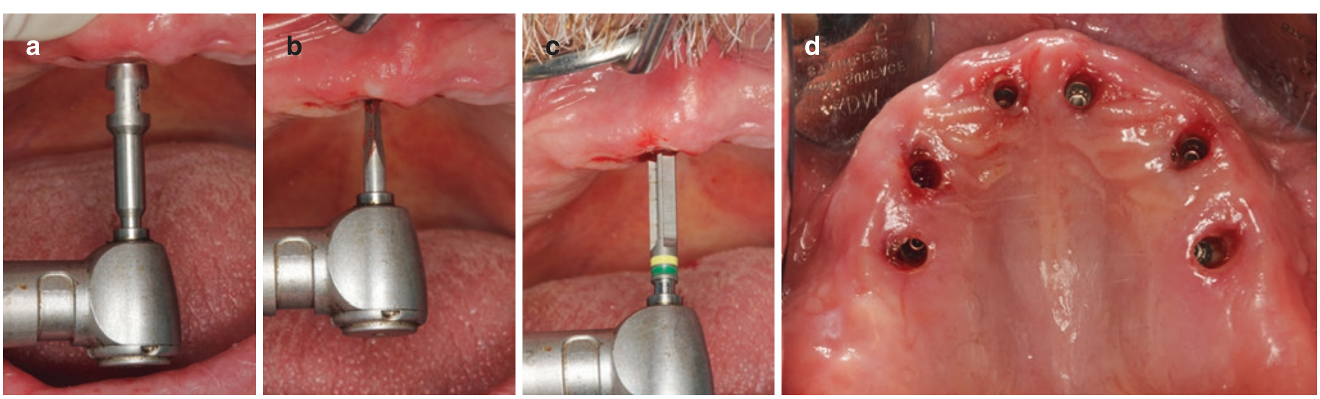


Fig. 72 Flapless surgery: (**a**) incision with punch, (**b**) initial drill, (**c**) final drill, and (**d**) inserted implants

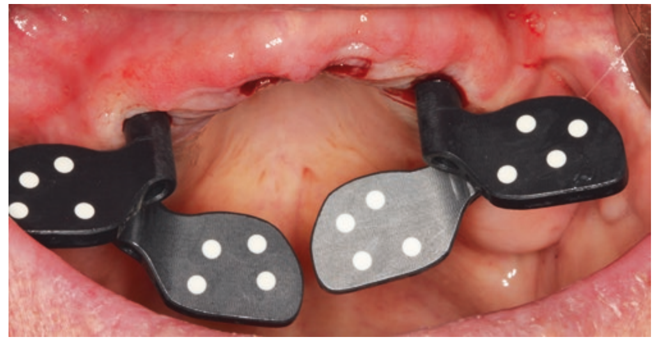


Fig. 73 PIC Abutments® placed to register implant positions. PIC Camera® registers the implant position through these abutment types

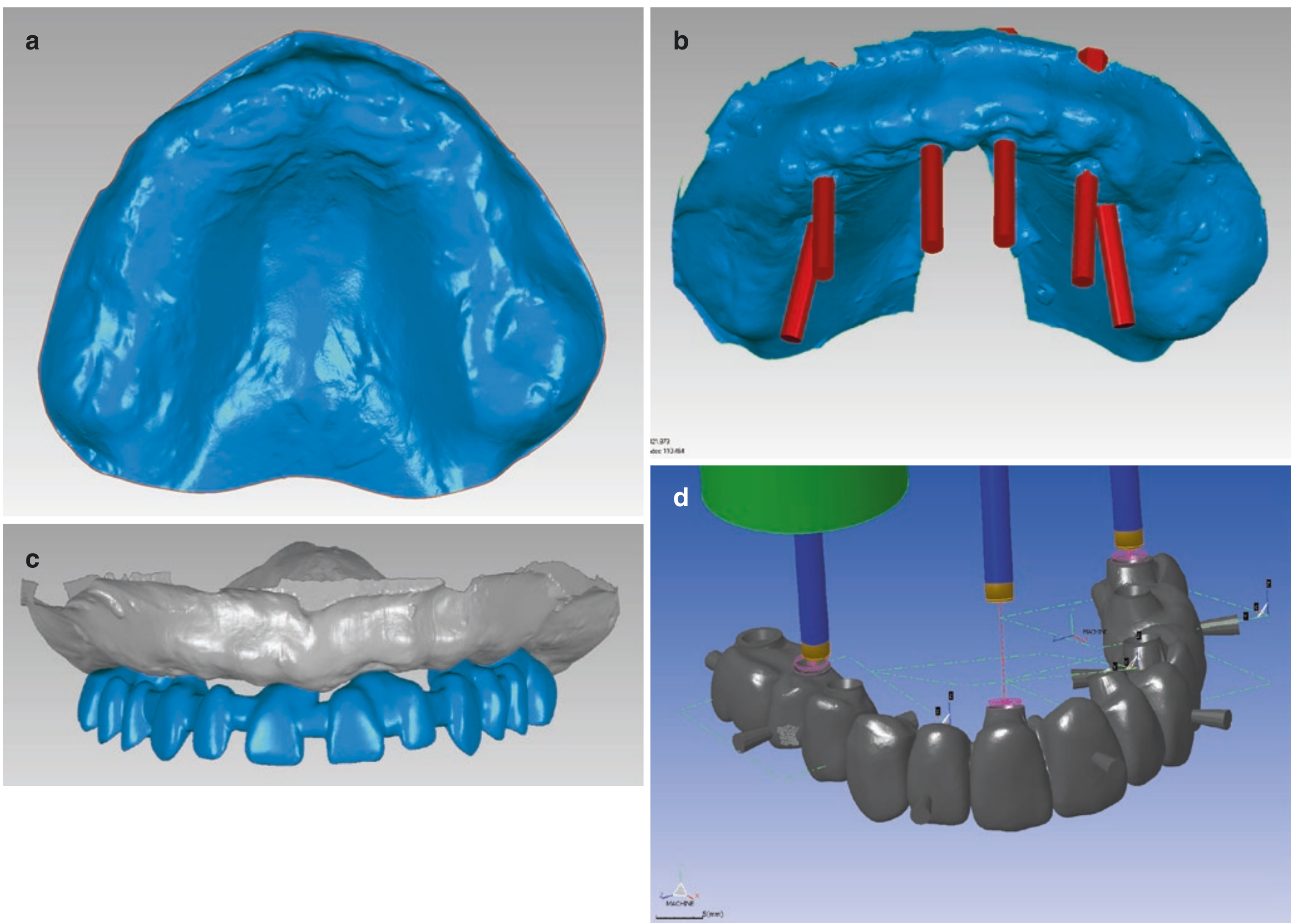


Fig. 74 (**a**) Digitalized impression of the soft tissues. (**b**) STL file containing the soft tissues and the position of the implants obtained with the PIC Camera® after alignment of the two files by best fit. (**c**, **d**) Design of the metal structure of the definitive prosthesis

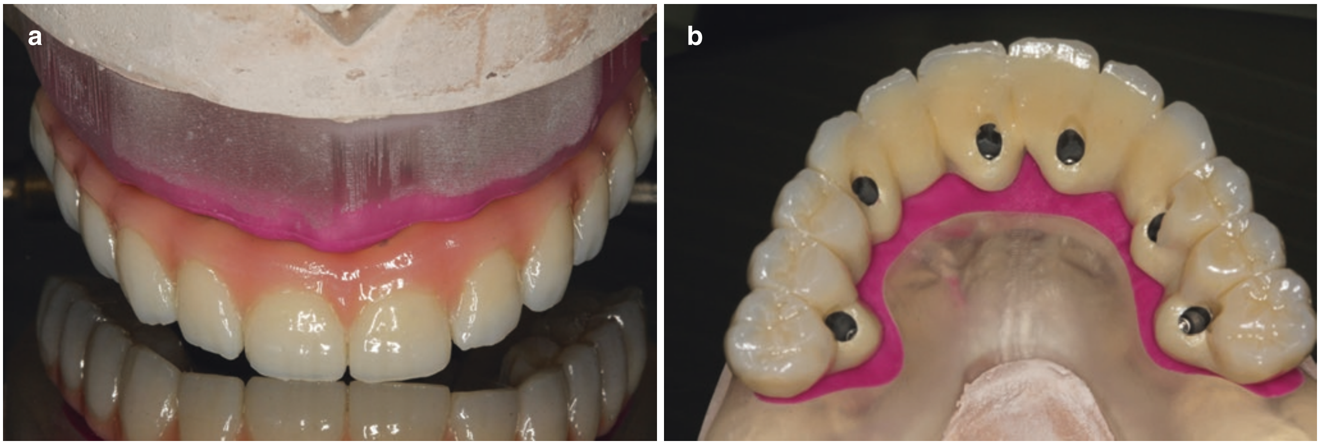


Fig. 75 Prosthesis on the stereolithographic models. (**a**) Frontal and (**b**) occlusal view

Fig. 76 Immediate loading prosthesis screwed to the implants: (**a**) intraoral frontal, (**b**) intraoral occlusal, and (**c**) extraoral view

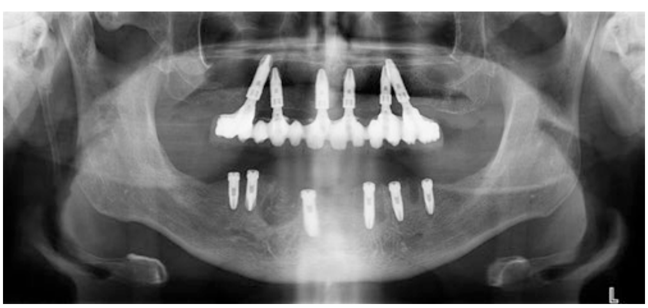


Fig. 77 The correct fit of the metal to the implant connection was evaluated using a panoramic radiograph. The implants were Ticare Mozo Grau® (Valladolid, Spain)

lithography (STL) format and milled. A 3D stereolithographic cast is printed for the placement of the ceramic or resin of the prosthesis (Figs. 74a–e and 75a, b).

The prosthesis is finally screwed to the implants with a torque of 30 Ncm (Fig. 76a–c). The correct fit of the metal to the implant connection is evaluated using a panoramic radiograph (Fig. 77).

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Immediate Loading in Atrophic Jaws: Zygomatic Implants

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Take-Home Message

– The rehabilitation of atrophic maxillas with zygomatic implants and immediate loading is a predictable treatment option that shortens treatment time, reduces treatment costs, and improves patient satisfaction. Nevertheless, it is a demanding treatment option that requires high surgical skills and experience to avoid or, in the event of happening, manage the complications that can be severe.

Introduction

PI Brånemark introduced the concept of zygomatic implants in 1989 using the zygoma bone, away from the alveolar ridge, as anchorage for oral rehabilitation. In 1998, after proven clinical success, this implant started to market (Brånemark 1998; Brånemark et al. 2004). The zygomatic fixture is an extended length (35–55 mm) titanium implant, placed into the zygomatic and maxillary alveolar bone. It was designed for situations where atrophy of the posterior maxilla complicates or prevents the placing of conventional implants (Vrielinck et al. 2003; Parel et al. 2001; Stevenson and Austin 2000). The use of zygomatic implants avoids the need for bone grafting, shortens treatment times, and reduces morbidity. Widmark et al. in 2001 obtained a survival rate of 74% after 3–5 years of follow-up in patients with bone grafts and conventional implants, while treatment with implants placed in unusual locations provided an 87% success rate (Widmark et al. 2001).

Zygomatic implants have been used in atrophic posterior maxilla and in cases with pneumatization of the maxillary sinus (Bedrossian and Stumpel 2001; Stevenson and Austin 2000), avoiding the need for bone grafts in the posterior area (Boyes-Varley et al. 2003b). They have also been used in patients with maxillectomies resulting from tumors or diseases associated with atrophic conditions of the maxilla (Weischer et al. 1997; Tamura et al. 2000). It was also indicated for those who preferred to avoid multiple surgeries and extended treatment times for healing and subsequent implant placement. It also eliminated the need to employ long-term transitional removable prosthesis prior to fabrication of the final prosthesis (Tuminelli et al. 2017).

The original Brånemark protocol consisted in the placement of two zygomatic implants bilaterally in the posterior maxilla and four additional axial implants in the premaxilla. Following a submerged healing period of 6 months, a final fixed dental prosthesis was made. This approach achieves a high implant survival rate of 94% and a prosthetic success rate of 96% after 5 years (Brånemark et al. 2004). The two major limitations of this approach were the palatally emergence of the prosthetic abutment, which can cause speech alterations, tongue irritation, and hygiene difficulties, and the intrasinus pathway of the implant, which was associated with asymptomatic sinus mucosal alterations and sometimes sinusitis (Davó et al. 2008a).

With the development of new surgical techniques, the limitations of the original protocol were gradually solved, achieving a more natural implant emergence into the alveolar ridge and less invasiveness to maxillary sinus. Additionally, with the advance of the technique, a purely zygoma approach was used to rehabilitate patients with absence of the bone in the premaxilla. With this protocol, four zygomatic implants were placed (two in each zygoma). An adequate anterior-posterior

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distribution of its emergencies meets the biomechanical requirements for the use of a fixed full-arch prosthesis without the need for additional implants ("all-on-four zygoma" or "quad zygoma") (Davó and Pons 2013).

Immediate Loading with Zygomatic Implants

Balshi and Wolfinger first describe immediate loading of zygomatic implants in a case report published in 2003 (Balshi and Wolfinger 2003). After this initial mention, Chow and Bedrossian published the first case series in 2006 with 5 and 14 patients included, respectively. Both obtain an implant survival rate of 100% at 10 and 12 months of follow-up (Chow et al. 2006; Bedrossian et al. 2006).

We elaborated a literature review for this chapter, and Table 1 summarizes the implant survival rates of zygomatic implants immediately loaded. Of a total of 1040 patients treated with zygomatic (2179 implants) and regular implants (3117 implants), an implant survival rate of 95.12–100% and 94.9–100% is expected, respectively, up to 10 years. For patients treated with the all-on-four zygoma or quad zygoma

Table 1 Implant survival and complications of immediate loading zygomatic implants

Author/year	Patients	ZI implants	R implants	Follow-up (months)	SR ZI (%)	SR RI (%)	Prosthetic complications	Sinus complications
Bedrossian et al. (2006)	14	28	55	12–34	100	100	Provisional prosthesis fracture 2/14	NR
Duarte et al. (2007)	12	48	0	30	97.9	–	No	No
Davó et al. (2007)	18	36	68	6–29	100	95.6	No	1/18 patients
Davó et al. (2008b)	42	81	140	12–42	100	97	No	1/42 patients
Mozzati et al. (2008)	7	14	34	24	100	100	No	No
Maló et al. (2008)	29	67	57	6–18	98.5	100	NR	4/29 patients
Balshi et al. (2009)	56	110	391	9–60	96.37	97.2	NR	NR
Aparicio et al. (2010a)	20	36	104	36–48	100	100	No	No
Aparicio et al. (2010b)	25	47	129	24–60	100	99.2	Screw fracture 1/25 Prosthetic teeth fracture 5/25	No
Bedrossian (2010)	36	74	98	60–84	97.29/100	100	NR	3/36 patients
Chow et al. (2010)	16	37	53	6–24	100	NR	NR	No
Davó et al. (2010)	17	68	0	12	100	–	No	No
Stievenart and Malevez (2010)	10	80	0	6–40	96	–	NR	1/20 patients
Migliorança et al. (2011)	75	150	286	12	98.7	99.3	No	No
Balshi et al. (2012)	77	173	NR	12–120	96.5	NR	NR	NR
Maló et al. (2012)	39	92	77	36	100	100	No	6/39 patients
Migliorança et al. 2012	21	40	74	96	97.5	95.9	Metal bar broken	No
Sartori et al. (2012)	16	37	58	12	100	100	Screw fracture Screw loosening Abutment screw loosening Prosthetic tooth wear	No
Davó et al. (2013)	36	68	112	60	98.5	94.9	Change fixed prosthesis for overdenture 1/36 Extreme tooth wear 4/36	1/36 patients
Davó and Pons (2013)	17	68	0	36	100	–	Abutment screw fracture 1/17 Prosthesis fracture 2/17	2/17 patients
Aparicio et al. (2014b)	22	41	131	120	95.12	97.71	Framework fracture 2/22 Screw fracture 4/22 Screw loosening 4/22 Abutment screw loosening 3/22 Prosthetic teeth fracture 7/22	6/22 patients
Maló et al. (2014)	39	92	77	60	98.8	NR	Prosthetic fracture 2/39 Prosthetic teeth fracture 1/39 Screw loosening 3/39	6/39 patients
Bertolai et al. (2015)	31	78	74	20–60	97.5	100	NR	2/31 patients
Davó and Pons (2015)	14	56	0	60	100	–	Prosthesis fracture 2/14 Abutment screw fracture 1/14	2/14 patients
Maló et al. (2015)	352	747	795	6–84	98.2	97.9	Mechanical complications 156/352	7% (25)
Mozzati et al. (2015)	10	40	0	30–32	100	–	No	NR

concept, 80 patients treated with 360 zygomatic implants, an implant survival rate of 96–100% is expected up to 5 years. The most frequent mechanical complication is the fracture of the prosthesis or the veneering material. Screw loosening and screw fracture were two common complications too. Because the original protocol to insert zygomatic implants needs an intrasinusal approach, sinus complications are reported frequently in the literature associated with this procedure (Chrcanovic et al. 2016). In our review, of 764 patients, 63 (8.24%) suffered sinus complications. The main sinus complication was acute sinusitis followed by the formation of an oro-antral fistula. The treatment of the sinusitis consists in the administration of oral antibiotics. In cases that this measure is not enough, endoscopic surgery was done, consisting in the opening of the maxillary ostium to improve sinus drainage. In extreme cases or in the presence of oro-antral fistula that don't close, the explantation of the zygomatic implant is mandatory.

Treatment Plan for Immediate Loading in Atrophic Maxillas

According to Bedrossian et al. (2008), the maxilla can be divided into three zones: (1) the premaxilla, (2) the premolar area, and (3) the molar area (see chapter "Diagnosis and Planning in Immediate Loading: Implant Selection"). The clinician should determine the availability of bone in all three zones. Cone beam computed tomography can be used to determine the amount of bone in these zones as well as in the zygomatic arch, in both horizontal and vertical dimensions. Moreover, any pathology in these areas, as well as in the maxillary sinuses, needs to be verified preoperatively.

- Bone presence in zones 1, 2, and 3: Traditional four, six, or eight axial implants.
- Bone presence in zones 1 and 2: Four implants. Two anterior axial implants and two posterior-tilted implants guided by the anterior maxillary sinus wall. All-on-four protocol.
- Bone presence only in zone 1: Two anterior axial implants and two zygomatic implants bilaterally in molar/premolar area. All-on-four hybrid protocol.
- Insufficient bone in all zones: Four zygomatic implants. Quad zygoma or all-on-four zygoma.

In cases where the bone ridge is narrow, implants can be placed in a palatal position in the anterior or premolar zones. With this approach it is possible to achieve good primary implant stability and overcame the deficiency of a thin marginal crest (less than 4 mm wide). The placement of implants palatal to the alveolar crest in the maxilla allows maximum use of the available bone in patients with severe horizontal bone resorption, reducing patient morbidity compared to conventional augmentation procedures (Peñarrocha et al. 2009).

Clinical Procedures

Zygomatic Implants Surgical Procedure

When an all-on-four standard procedure cannot be performed due to the lack of bone in zones 2 (premolar) and 3 (molar) and even in zone 1 (premaxilla), the use of zygomatic implants is indicated to provide these patients with a fixed immediate load restoration.

The realization of a CBCT is mandatory to know the anatomy of the zygoma bone of the patient. The knowledge of the anatomy of this bone is extremely important, especially in the quad zygoma approach where two areas in the zygoma bone are necessary to host the apex of two implants.

The zygoma is an irregular bone with various thicknesses, and its characteristics are diverse between ethnicities and gender (Takamaru et al. 2016; Zhou and Wu 2001). In a recent study by Hung et al. (2017), the thickness of the zygoma ranged from 4.51 to 8.01 mm and the lengths from 25.67 to 32.54 mm; in female these measurements were smaller than in male. No differences were found between the zygoma bone of dentate and edentulous patients. Apart of the zygoma bone, the radiologic examination should include the maxilla, a full view of the maxillary sinuses, and the floor of the orbit. Information about the health of the sinuses, the opening of the meatus, and the position of the infraorbital nerve must be recorded (Malevez 2012).

Anesthesia

In the original protocol, general anesthesia with nasal intubation is required for the surgery. Local anesthetic (lidocaine with epinephrine 1:50,000) was infiltrated to block the superior alveolar nerves (posterior, middle, and anterior) and the palatal nerves (posterior and nasopalatal) and to obtain local hemostasis.

An alternative approach combining intravenous conscious sedation and local anesthesia can be used especially by experienced surgeons and in interventions that are expected to last less than 90 min (Peñarrocha et al. 2005; Aparicio et al. 2008). No differences were found regarding patient satisfaction between these two types of anesthetic procedures because both have high satisfaction. Nevertheless a conscious sedation procedure would be of choice regarding simplicity, economic cost, and the possibility to go home after surgery sooner (Almeida et al. 2017).

The intravenous sedation procedure requires the simultaneous use of local anesthetic procedure. The procedure starts with the infiltration anesthesia in the buccal vestibule from the central incisor to the third molar, using articaine with 1:100,000 epinephrine, the block of the palatal posterior nerve and the infraorbital nerve block. Also it is necessary to infiltrate anesthesia around the zygoma area through the skin or the oral mucosa.

Surgical Techniques

According to a recent systematic review (Chrcanovic et al. 2013), five different surgical techniques have been described in the literature for zygomatic implants: the classical approach or Brånemark approach, the sinus slot technique, the exteriorized approach, the minimally invasive approach by the use of custom-made drill guides, and the computer-aided surgical navigation system approach. In this chapter we are going to resume the first three, because these are still the most common approaches for the placement of zygomatic implants.

The Classical Approach

The original technique was first described by Brånemark in 1998 (Brånemark 1998) and was used by many other authors in several clinical studies (Parel et al. 2001; Bedrossian et al. 2002, 2006; Boyes-Varley et al. 2003a; Nakai et al. 2003; Brånemark et al. 2004; Hirsch et al. 2004; Malevez et al. 2004; Becktor et al. 2005; Ahlgren et al. 2006; Aparicio et al. 2006; Chow et al. 2006; Farzad et al. 2006; Aghabeigi and Bousdras 2007; Davó et al. 2007, 2008a, b, 2010; Duarte et al. 2007; Kahnberg et al. 2007; Mozzati et al. 2008; Pi-Urgell et al. 2008; Balshi et al. 2009; Davó 2009; Bedrossian 2010; Stievenart and Malevez 2010). The surgery starts with a vestibular incision similar to a LeFort I incision between first molar regions. A palatal flap is raised to expose the alveolar ridge and the entire hard palate. The nasal mucosa is dissected to increase visibility and to orient the surgeon into the local anatomy. The dissection is continued along the infrazygomatic crest toward the zygomatic bone. The infraorbital nerve is localized and the zygomatic region exposed. The periosteum of the medial part of the zygomatic body and the zygomatic arch is raised. A window (5 × 10 mm) is opened in the uppermost lateral aspect of the sinus wall in the extension of the infrazygomatic crest, using a round bur. The sinus mucosa is then elevated with no special effort to keep it intact. The window provides direct visibility of the roof of the sinus and allows localization of the optimal point for entrance of the drill into the zygoma bone. From a prosthetic point of view, the optimal entrance is as far posterior and close to the alveolar ridge as possible. The entrance on the palatal side of the crest is marked, and a round bur (Ø 2.9 mm) is used to penetrate the crest and mark the entrance in the roof of the sinus. The entire site in the zygoma is then prepared with a twist drill (Ø 2.9 mm). A 3.5-mm pilot drill is then used to enlarge the site. To ensure that the wider drill does not deviate from the planned direction, it is equipped with a non-cutting tip 2.8 mm in diameter. The preparation continues with a 3.5-mm twist drill with a cutting apex. A depth indicator is inserted into the site to decide the correct length of the zygoma fixture. A 4-mm countersink drill may be used only when the palatal bone is thick or dense because of the risk of excessive widening of the palatal entrance. The zygomatic implant is inserted slowly until its apical portion is anchored in the zygoma bone, and it is manually inserted to adequate depth and positioned in an optimal way from the prosthetic point of view. The muscles that were released from the lower anterior aspect of the zygoma should be carefully repositioned to avoid the formation of a retrozygoma space. The submucous tissue should be reattached with individual absorbable sutures that connect to the lateral horizontal incision over the distal aspect of the maxilla, so that tissue with periosteum provides a cover over the window in the upper anterior maxillary body. The initial incision is then closed with individual mattress non-absorbable sutures. In this protocol, adequate alveolar bone must be present in the anterior maxilla to allow the placement of two to four anterior maxillary implants combined with the zygomatic implants (Brånemark 1998; Brånemark et al. 2004).

The Sinus Slot Approach

The sinus slot technique was introduced by Stella and Warner in 2000 (Stella and Warner 2000) and has been used by other authors in clinical studies (Ferrara and Stella 2004; Peñarrocha et al. 2005, 2007; Davó et al. 2008a, b). The operative technique begins with a crestal incision extending from one maxillary tuberosity to the contralateral tuberosity. A vertical-releasing incision is made bilaterally at the posterior extent of the incision. Thus it extends around the base of the piriform rim, up to the inferior aspect of the infraorbital nerves, and around the inferior halves of the body of the zygomas. The palatal mucosa is reflected only to expose the bone crest. A fissure bur is then used to make a hole through the bone and into the sinus cavity at the superior extent of the contour of the zygomatic buttress. The depth gauge is placed in the bur hole and positioned to simulate the angle of approach of the implant twist drill. A second bur hole is made on this line 5 mm above the crest of the ridge. A slot is then made that connects the two bur holes. The superior aspect of the slot extends to the base of the zygoma, while the inferior extent of the slot approximates the floor of the maxillary sinus. This slot is made directly through the buttress wall without concern of compromise to the sinus membrane. The slot results in a smaller antrostomy than the classical technique but will serve to orient the twist drills for implant placement. With a round bur, a small point is marked at the ideal location on the crest of the maxillary ridge, which lines up with the sinus slot. This places the implant abutment in the first molar region. The tip of the zygomatic twist drill (Ø 2.9 mm) is placed directly over the crest of the ridge, and the drill is directed such that it extents directly through the sinus slot that was previously fabricated. The tip of the drill is guided through the center of the slot under direct visualization. The drill is advanced superiorly toward the junction of the lateral orbital rim and zygomatic arch. The 3.5-mm pilot drill and 3.5-mm twist drill are then used in the same fashion, being directed through the center of the sinus slot. The depth of preparation is checked with the depth gauge, and the appropriate implant length is chosen. As the implant is being placed, it can be seen directly as it cuts threads on either side of the sinus slot (Stella and Warner 2000). Two cases treated with this approach were showed in Figs. 1, 2, 3, 4, 5, 6, and 7.

The Exteriorized Approach

The exteriorized approach was first described by Migliorança et al. in 2006 (Migliorança et al. 2006) and is also called "extramaxillary" or "extrasinus zygomatic implants" (Migliorança et al. 2006, 2011; Maló et al. 2008; Aparicio et al. 2010a; Chow et al. 2010). A midcrestal incision from one tuberosity to the other was done, along with two vertical-releasing incisions in the zygomatic pillar region. A mucoperiosteal flap is elevated, allowing visualization of anatomical structures. The zygomatic implants are placed outside the sinus, contacting the outer aspect of the lateral wall of the maxillary sinus, as distal as the anatomy of the patient allows, in the second premolar or first molar region. No maxillary antrostomy is necessary. The zygomatic implant osteotomy begins with a spherical drill, which penetrates the residual ridge near to the top of the crest, from palatal to buccal. The drill transfixes the crest and emerges in the buccal aspect of the ridge, external to the maxillary sinus. The drilling continues toward the zygoma bone along the outer aspect of the lateral wall of the maxillary sinus until it reaches the zygoma in its lateral portion. With the same drill, the zygomatic bone is perforated until the outer cancellous layer of the bone is surpassed. The depth indicator is then used to determine the length of the zygomatic implant. The osteotomy is progressively widened using the usual drill sequence. Then, the implants were placed and the insertion is completed manually. The zygomatic implant platform emerges over or close to the top of the crest of the residual alveolar ridge (Migliorança et al. 2006, 2011).

This technique is especially indicated in those patients with pronounced buccal concavities on the lateral aspect of the maxillary sinus, in whom the use of the original technique with an intrasinus path results in excessive palatal emergence of the implant head. This commonly results in a bulky dental bridge at the palatal aspect, which sometimes leads to discomfort and problems with oral hygiene and

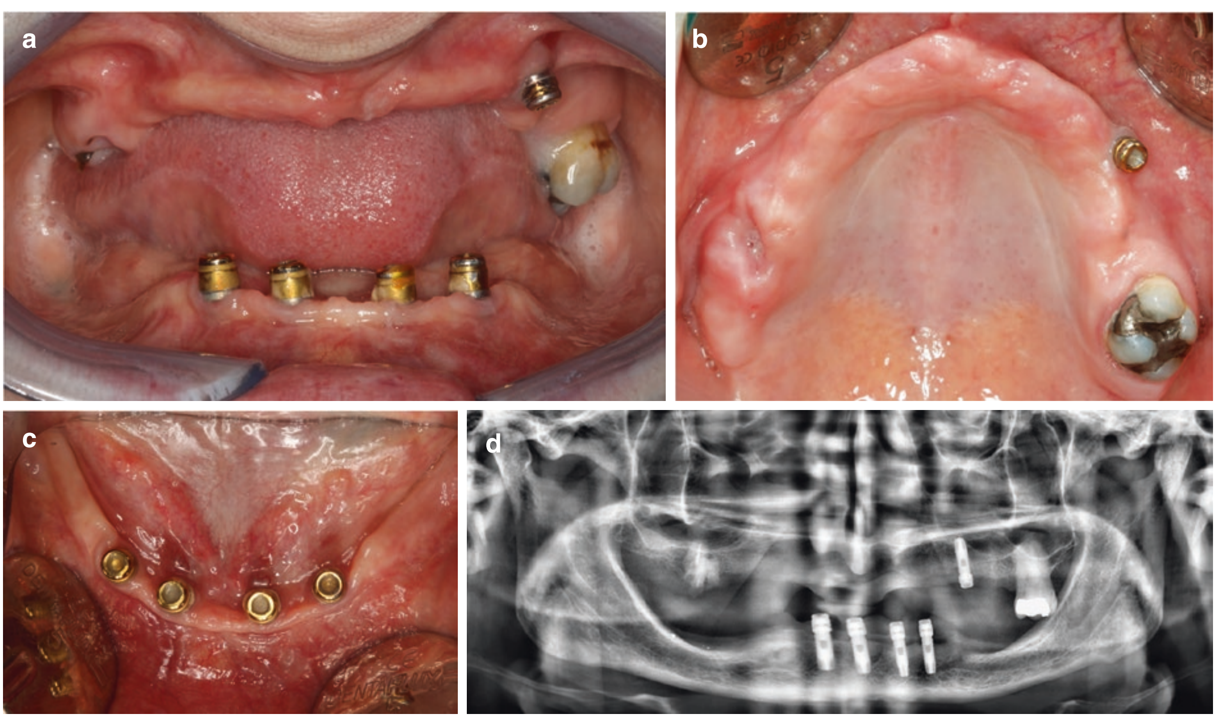


Fig. 1 Initial situation of the patient. (**a**) Frontal and (**b** and **c**) occlusal intraoral view. (**d**) Initial panoramic x-ray. The patient lost his/her upper implants and presents an extreme atrophy of the maxilla (Class VI Cawood and Howell) with no bone in zones 1, 2, and 3

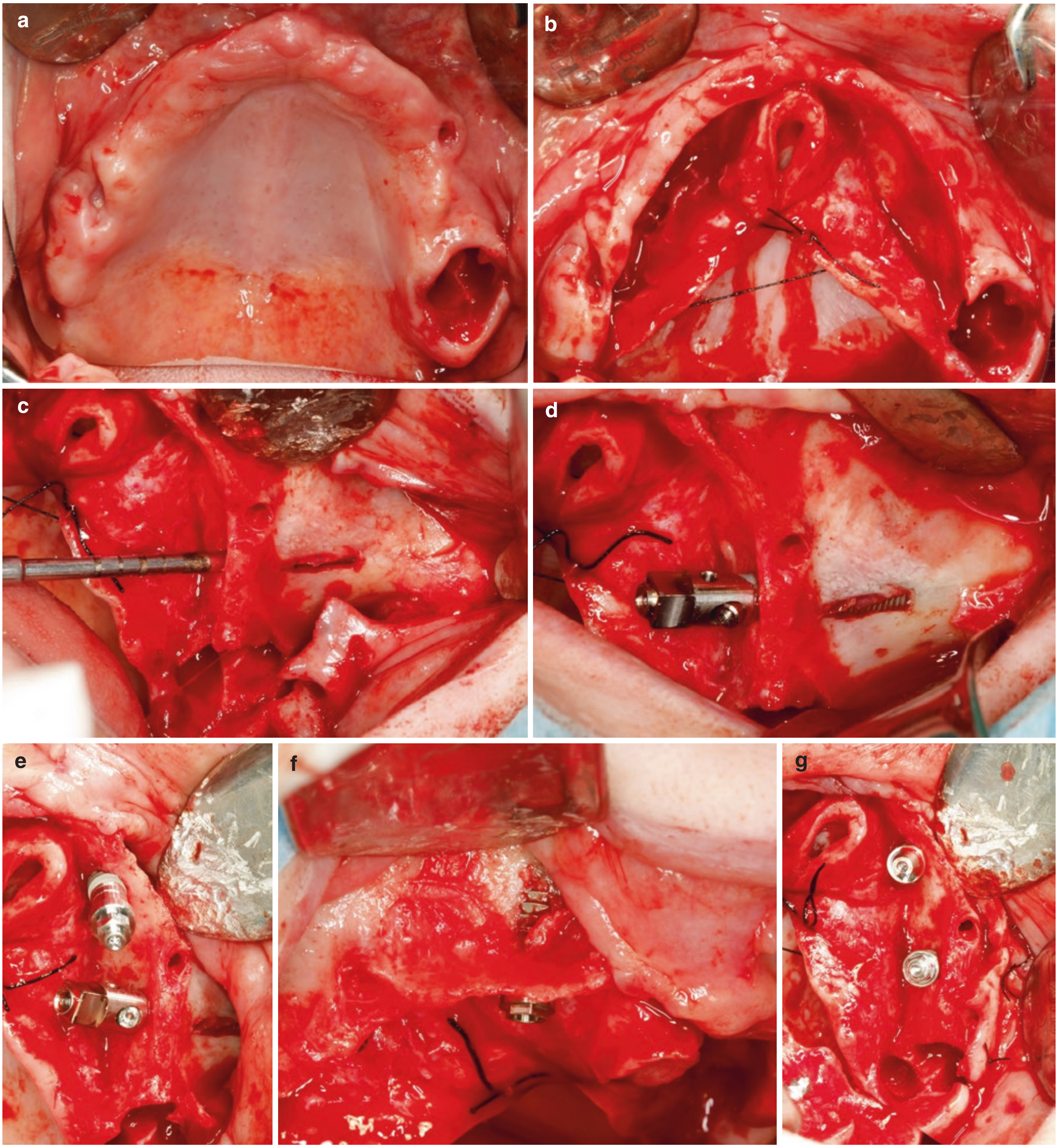
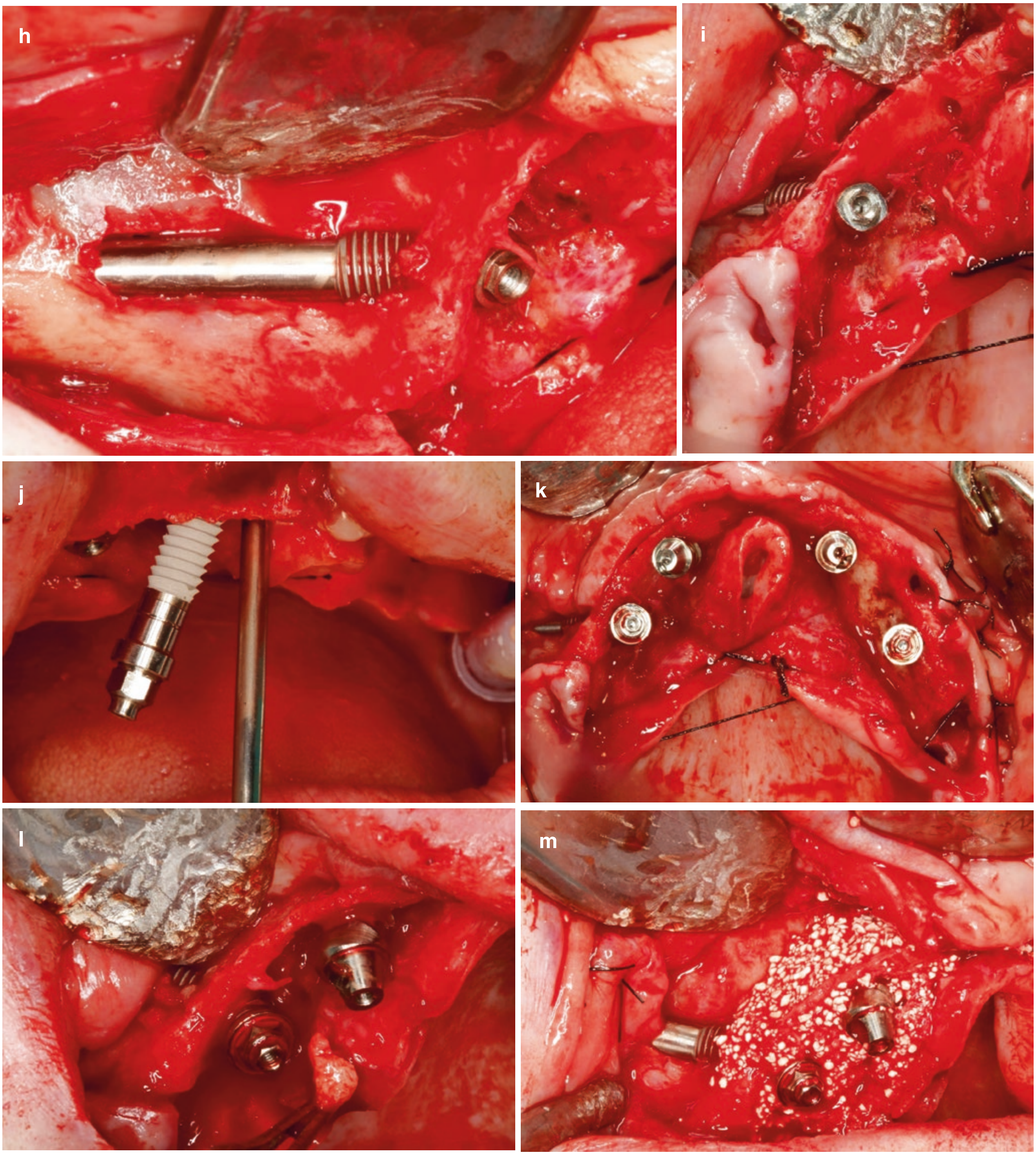


Fig. 2 Surgery. (**a**) Extraction of remnants tooth and implant. (**b**) Flap elevation. (**c** and **d**) Placement of the left zygoma implant using the sinus slot approach (Branemårk System™ Zygoma TiUnite, Nobel Biocare, Gothebörg, Sweden). (**e** and **f**) Placement of the anterior left implant. The implant was placed pallatally and tilted. The tip of the implant reaches the vomer bone, an anatomical buttress that can be used in patients with extreme bone resorption (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**g**) Aspect of the implants of the left maxilla. (**h** and **i**) Placement of the right zygoma implant using the sinus slot approach. (**j**) Detail of the placement of the anterior right implant. The left implant is tilted anteriorly searching the vomer bone. A probe was place in the nasopalatine foramen to see the direction and angulation of the implant (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**k**) Detail of the four implants in place. Two zygoma implants and two anterior implants. (**l**) Placement of the prosthetic abutments. (**m**) Bone regeneration using an alloplastic material covering the exposed threads both buccal and palatal (Mimetik Oss®, Mimetis Biomaterials, Cerdanyola del Vallès, Barcelona, Spain). (**n**) A resorbable collagen membrane was placed covering the graft (Creos™ Xenoprotect, Nobel Biocare, Gothebörg, Sweden) and (**o**) fixed with resorbable mattress sutures. (**p** and **q**) Additionally, a pedicle connective tissue graft from the palate was used to cover the bone regeneration. (**r**) Primary closure of the flaps. (**s**) Postoperative panoramic x-ray showing the two zygoma implants and the two anterior implants. (**t**) CBCT 3D reconstruction with implants in place. (**u** and **v**) Coronal CBCT images taken postoperatively and 1 month later. See that a normal transient inflammatory response of the sinus membrane is usual after intrasinus zygoma implant placement. After 1 month the inflammatory response decreases and tends to resolve spontaneously



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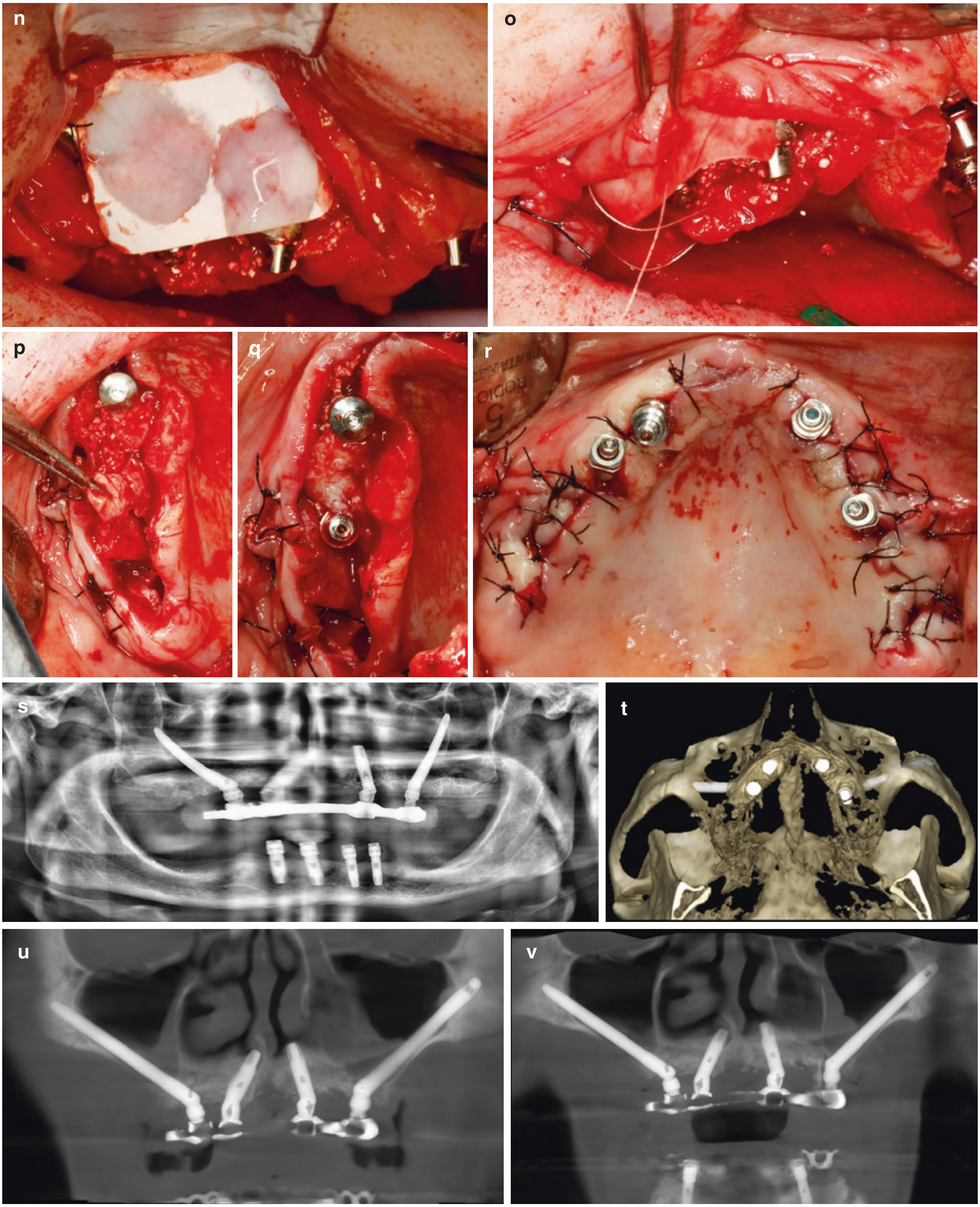

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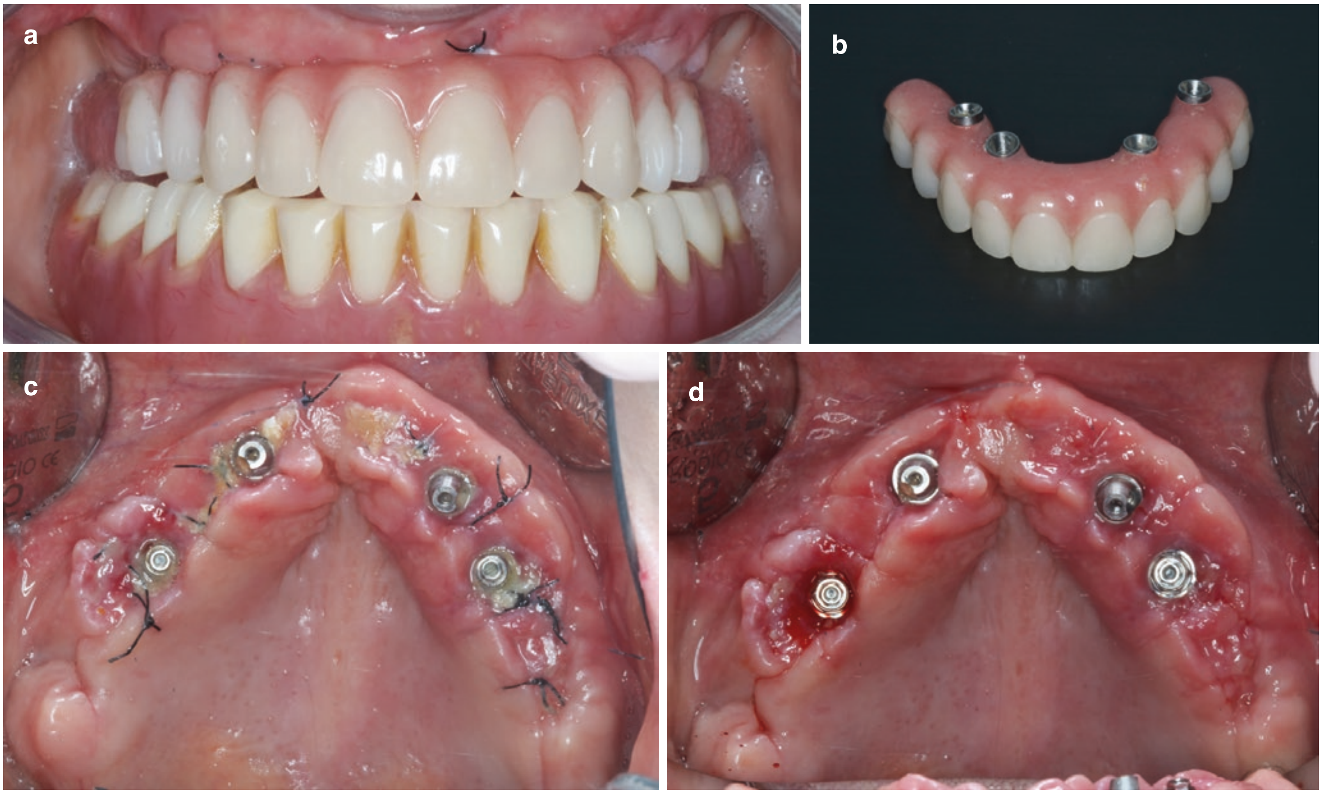


Fig. 3 (**a**) Aspect of the temporary prosthesis 1 week after its placement, at suture removal. (**b**) Detail of the temporary prosthesis. The base must be flat or concave to model the tissues and to allow a proper oral hygiene. (**c**) Aspect of the soft tissues at 1 week after prosthesis removal. (**d**) Aspect of the soft tissues after suture removal at 1 week. See that the pressure of the prosthesis started modeling the peri-implant mucosa

Fig. 4 Initial situation of the patient. The patient was rehabilitated with two implant-retained overdentures and wants to change for a fixed one. (**a** and **b**) Extraoral aspect of the patient. (**c**–**e**) Intraoral aspect. The lower implants were affected by peri-implantitis. (**f**) Initial panoramic x-ray. The patient presents a severe atrophy of the upper maxilla with pneumatization of the maxillary sinus and no bone in the premaxilla

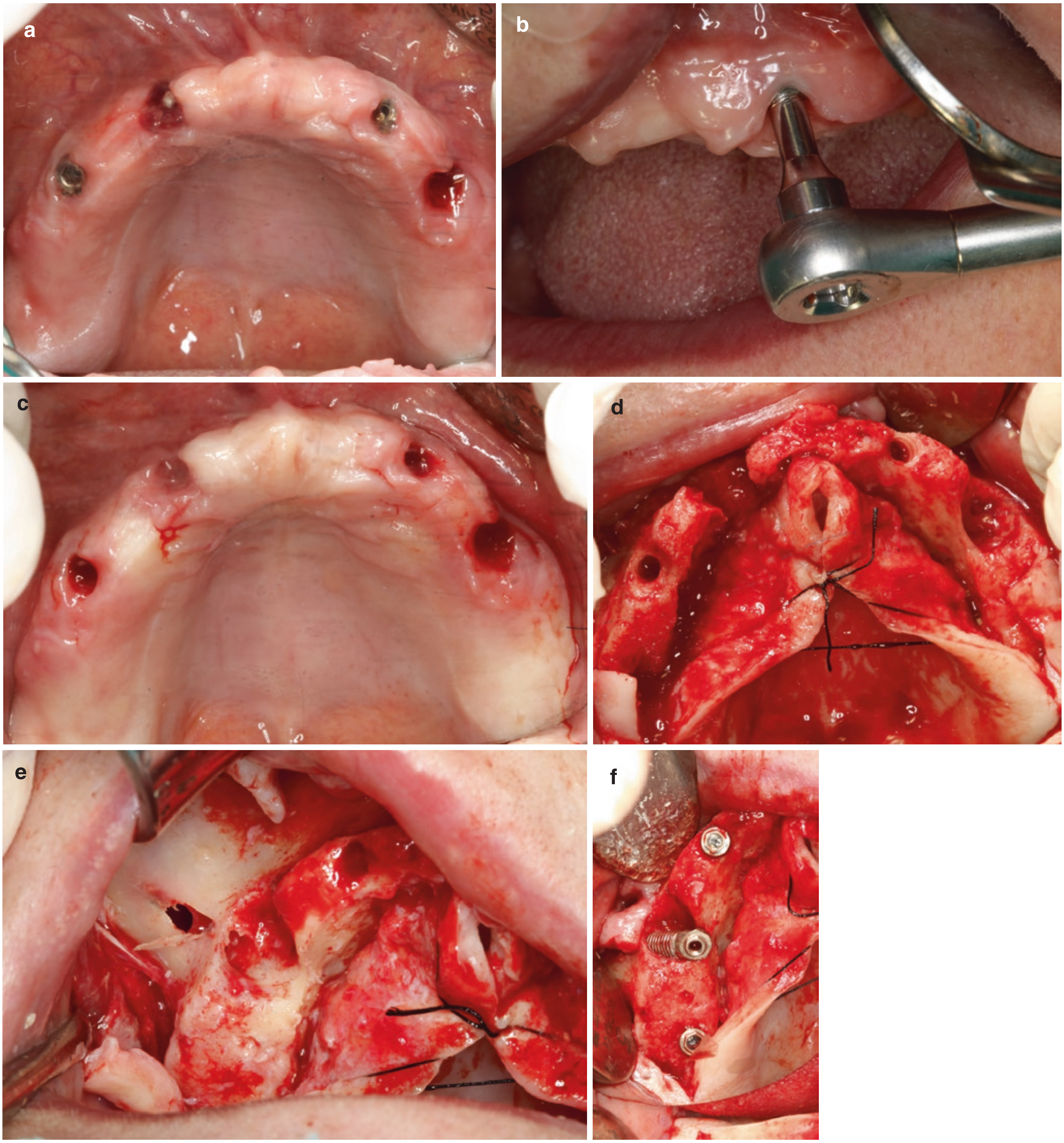
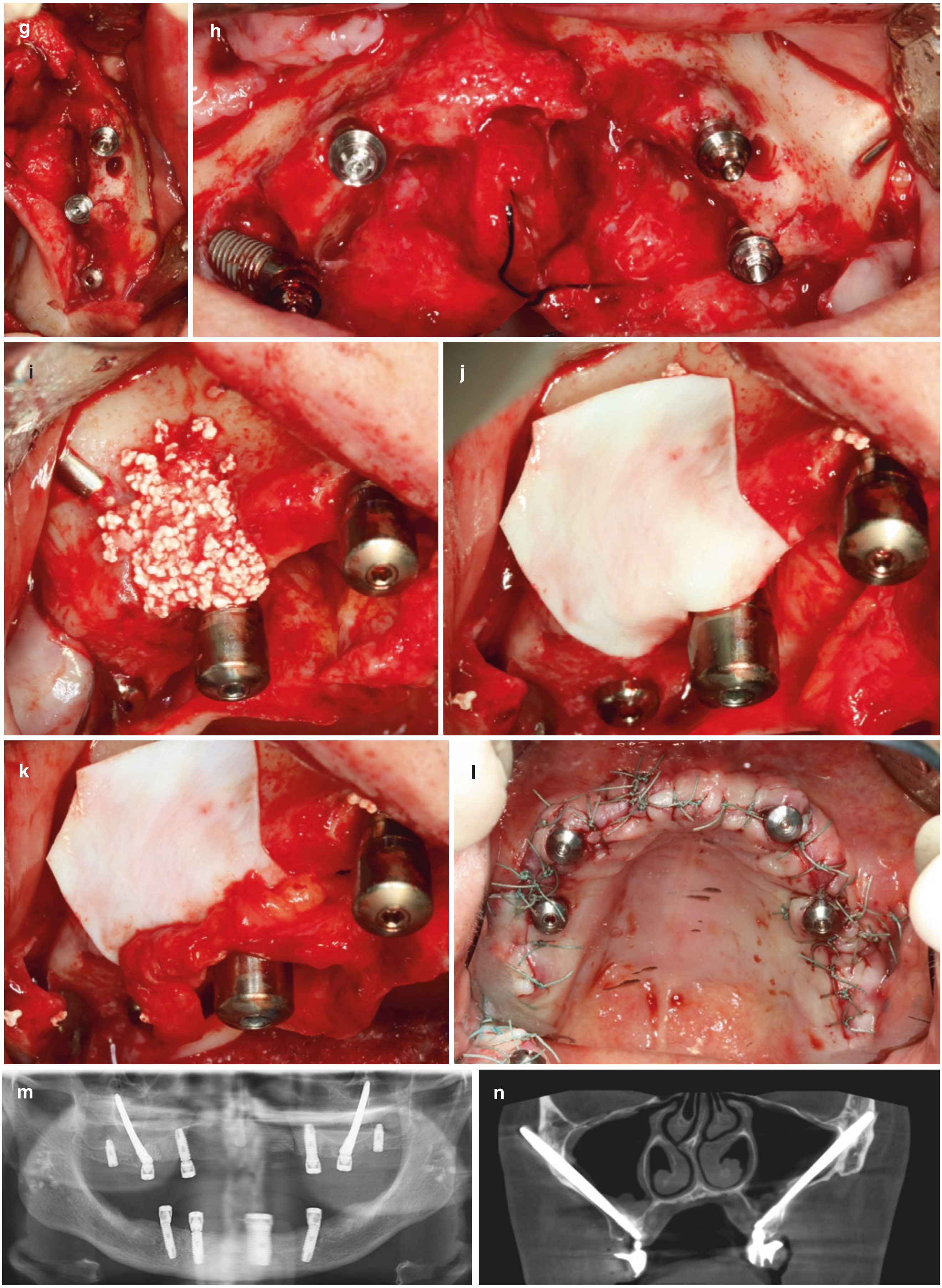


Fig. 5 Surgery. (**a**) Removal of the implants bars. One implant came out together with the bar. (**b**) Detail of the explantation. (**c**) Aspect after implant explantation. (**d**) Full-thickness flap elevation. See the big defect present in the premaxilla. (**e–g**) Preparation and placement of zygoma implants using the sinus slot approach. Two anterior implants were placed using the frontomaxillary buttress. In addition, two rescue implants were placed using the sinus septum as anchorage. These two implants were not used for immediate loading (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**h**) Detail of the zygoma implants and the two anterior implants. (**i** and **j**) A guide bone regeneration procedure using an alloplastic material the next biomaterial brand: (KeraOs®, Keramat, Ames, A Coruña, Spain) and a resorbable collagen membrane was used to regenerate a peri-implant dehiscence affecting the right zygoma implant (Creos™ Xenoprotect, Nobel Biocare, Ghoteborg, Sweden). (**k**) A pedicle connective tissue graft was used like a "scarf" around the neck of the implant to obtain a keratinized mucosa around the right zygoma implant. (**l**) Flap suture. (**m**) Postoperative panoramic x-ray showing the two zygoma implants, the two anterior implants placed in the frontomaxillary buttress and the posterior implants anchoraged in sinus septa. (**n**) CBCT coronal image of the two zygoma implants



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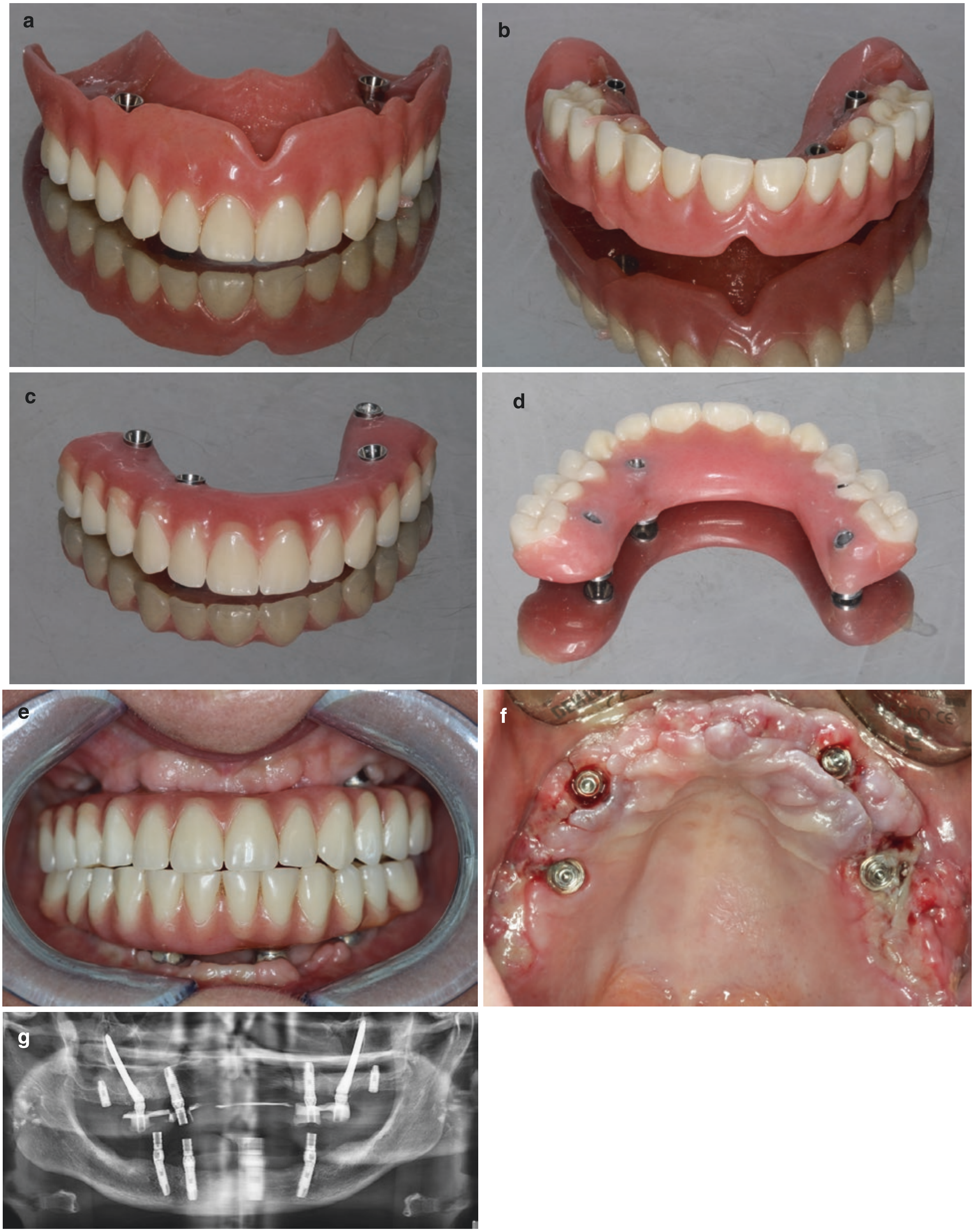


Fig. 6 (**a** and **b**) Temporary titanium abutments were fixed with resin to a previously made removable complete denture. (**c**) All the internal part of the prosthesis was filled with pink resin to the base of the temporary abutments and polished. A flat surface was created to model soft tissues and improve the oral hygiene. (**d**) The temporary titanium abutments were cut and the occlusion was adjusted (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**e**) Aspect of the temporary rehabilitation. (**f**) Aspect of soft tissues at 1 week. (**g**) Panoramic x-ray at 4 months of control at the moment of beginning the definitive rehabilitation

Fig. 7 (**a–c**) Extraoral aspect of the definitive rehabilitation. (**d–f**) Intraoral aspect of the definitive rehabilitation. (**g**) Panoramic x-ray at definitive prosthesis delivery. See the perfect adjustment of both prostheses. The two posterior upper implants were not used and maintained asleep. In the mandible an all-on-four procedure was performed. (**h**) Aspect of the soft tissues at definitive prosthesis delivery

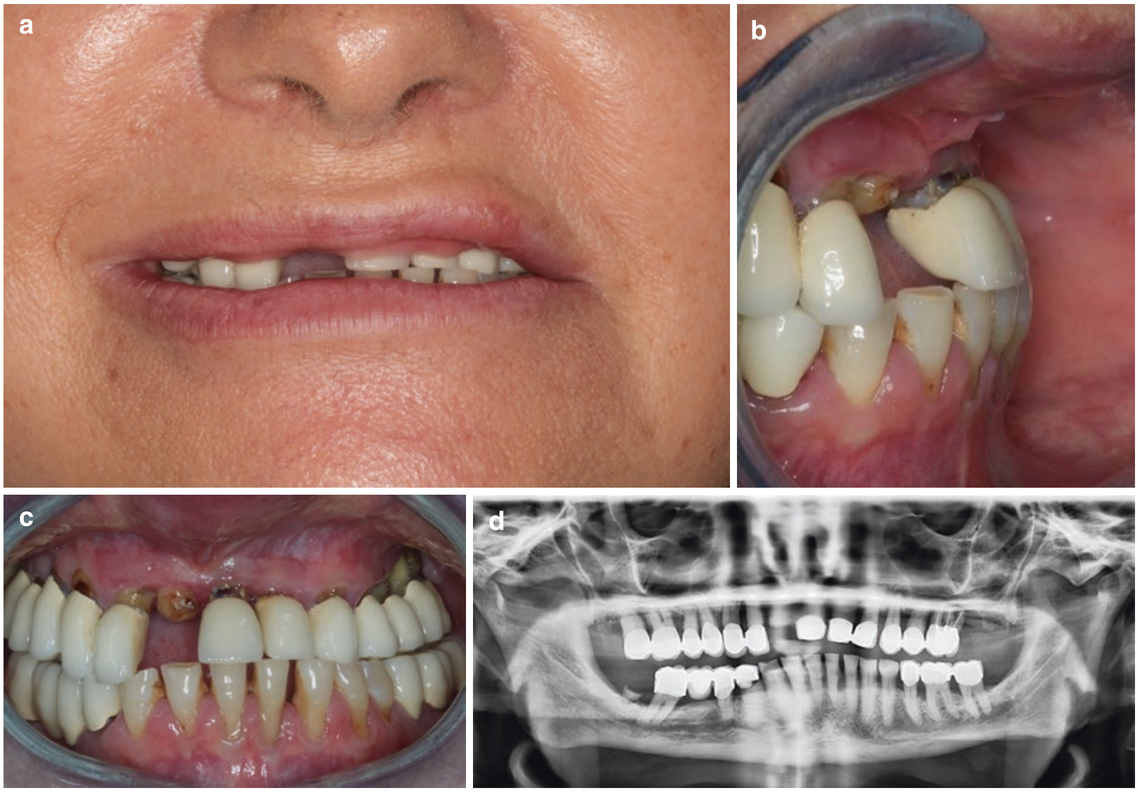


Fig. 8 Initial patient situation. (**a**) Extraoral aspect of the patient. (**b** and **c**) Intraoral aspect of the patient. The patient presents with severe periodontal disease, numerous crown misfits, and tooth decay. (**d**) Caused by a poor prognosis, it was decided to extract remnant teeth of the maxilla and do a fixed rehabilitation on implants

speech (Boyes-Varley et al. 2003b; Al-Nawas et al. 2004; Becktor et al. 2005; Farzad et al. 2006). Figures 8, 9, 10, 11, 12, 13, 14, 15, and 16 show three cases treated with this approach.

Selection of the Surgical Technique for Zygomatic Implants

The selection of the surgical technique must take into consideration the concavity formed between the alveolar crest, the maxillary sinus wall, and the region of the zygoma where the implants are going to be placed, as well as surgeon preference. When this concavity is small, the original classical technique or the sinus slot technique should be more indicated because of the anatomical impossibility to exteriorize the implant. Of these two, the sinus slot is of preference because it is less invasive. When a more pronounced concavity exists, it would be better to exteriorize the zygomatic implant or use the sinus slot technique. At this respect, Aparicio in 2011 suggest a classification (zygoma anatomy-guided approach (ZAGA)) of the anatomy of the maxillary-zygomatic complex to guide the selection of the surgical technique based on the relation between the alveolar crest, the zygoma, and the concavity they formed (Aparicio 2011; Aparicio et al. 2014a).

The exteriorized approach, when possible, should be considered as the technique of choice, as it has fewer surgical steps than the classical and sinus slot techniques, is less invasive, and reduces surgical time. As an alternative technique or when anatomy does not permit the exteriorized approach, the sinus slot technique is of choice (Chrcanovic et al. 2013).

Rehabilitation of Atrophic Maxillas with Zygomatic Implants

All-on-Four Hybrid

The all-on-four hybrid treatment protocol is indicated when the maxilla of the patient doesn't have enough bone in zones 2 (premolars) and 3 (molars) for axial implant placement, but the bone is available in zone 1 (premaxilla). In this type of cases, the tilted posterior implants used in the all-on-four standard protocol cannot be used because their emergence would be at cuspid level, and consequently a very short prosthetic arch length can be obtained.

The all-on-four hybrid treatment protocol consists in the use of zygomatic implants anchored in the zygoma bone to provide posterior support to the prosthesis combined with the placement of anterior regular implants in the premaxilla. This technique was called hybrid and described by

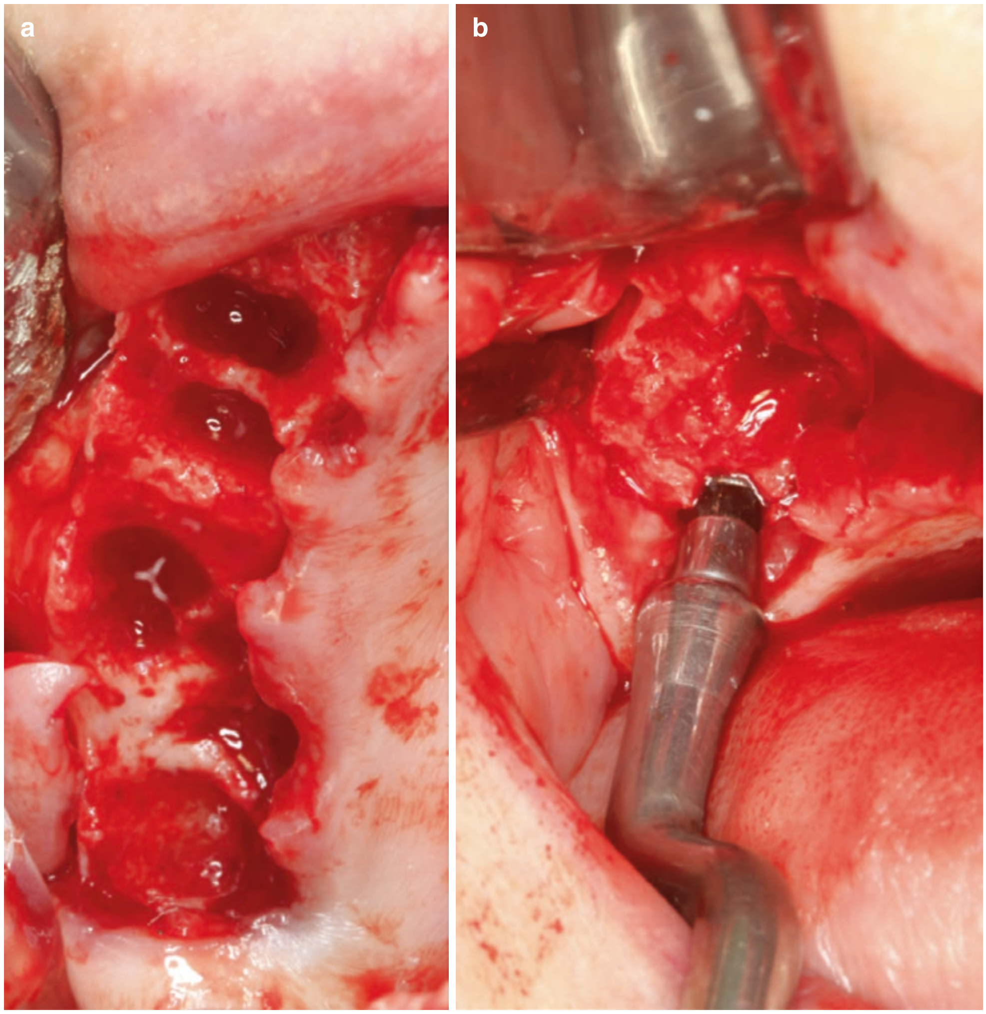
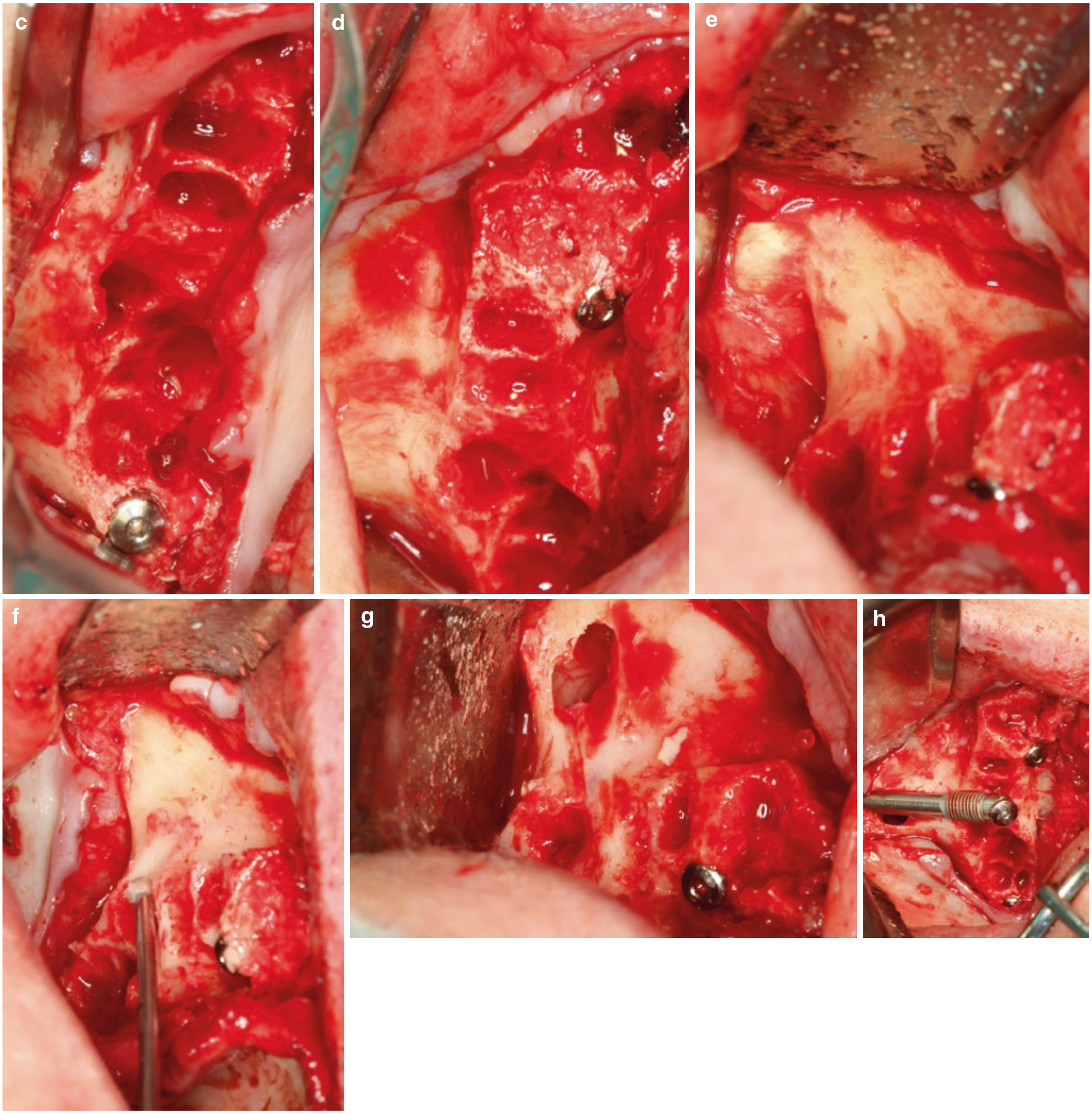


Fig. 9 Surgery. (**a**–**c**) After teeth extraction, a pterygoid implant was placed on the right side of the maxilla using a combination of drills and osteotomes. The same procedure was done on the left side. (**d**) An implant in the frontomaxillary buttress was placed too on the right side. (**e**–**h**) Preparation and placement of the right zygoma implant using the exteriorized approach. (**i** and **j**) Preparation of the left zygoma implant using the exteriorized approach. (**k**) Aspect of the two zygoma implants placed using the exteriorized approach and the two implants placed in the frontomaxillary region. See that the anterior implants were placed palatally to preserve a thick buccal bone. (**l** and **m**) A pedicle connective tissue graft was used like a "scarf" in both zygoma implants to obtain a thick keratinized mucosa around implants. (**n**) Flap suture. An additional implant was placed in the nasopalatine canal to perform an immediate loading protocol, caused by a low primary stability of the right frontomaxillary implant. (**o** and **p**) Temporary titanium abutments were placed to perform a bite register and sent to the dental technician for mounting the models. (**q**–**s**) The impression abutments were placed and splinted and an open tray impression was made. (**t**) Detail of the temporary prosthesis sent by the dental technician. (**u**) Intraoral and (**v**) extraoral aspect of the temporary prosthesis. (**w**) Aspect of soft tissues at 1 week of suture removal. (**x**) Postoperative panoramic x-ray. The immediate loading was performed using the zygoma implants, the left frontomaxillary implant, and the implant placed in the nasopalatine canal. The two pterygoid implants and the right frontomaxillary implant were left for a submerged healing (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain)



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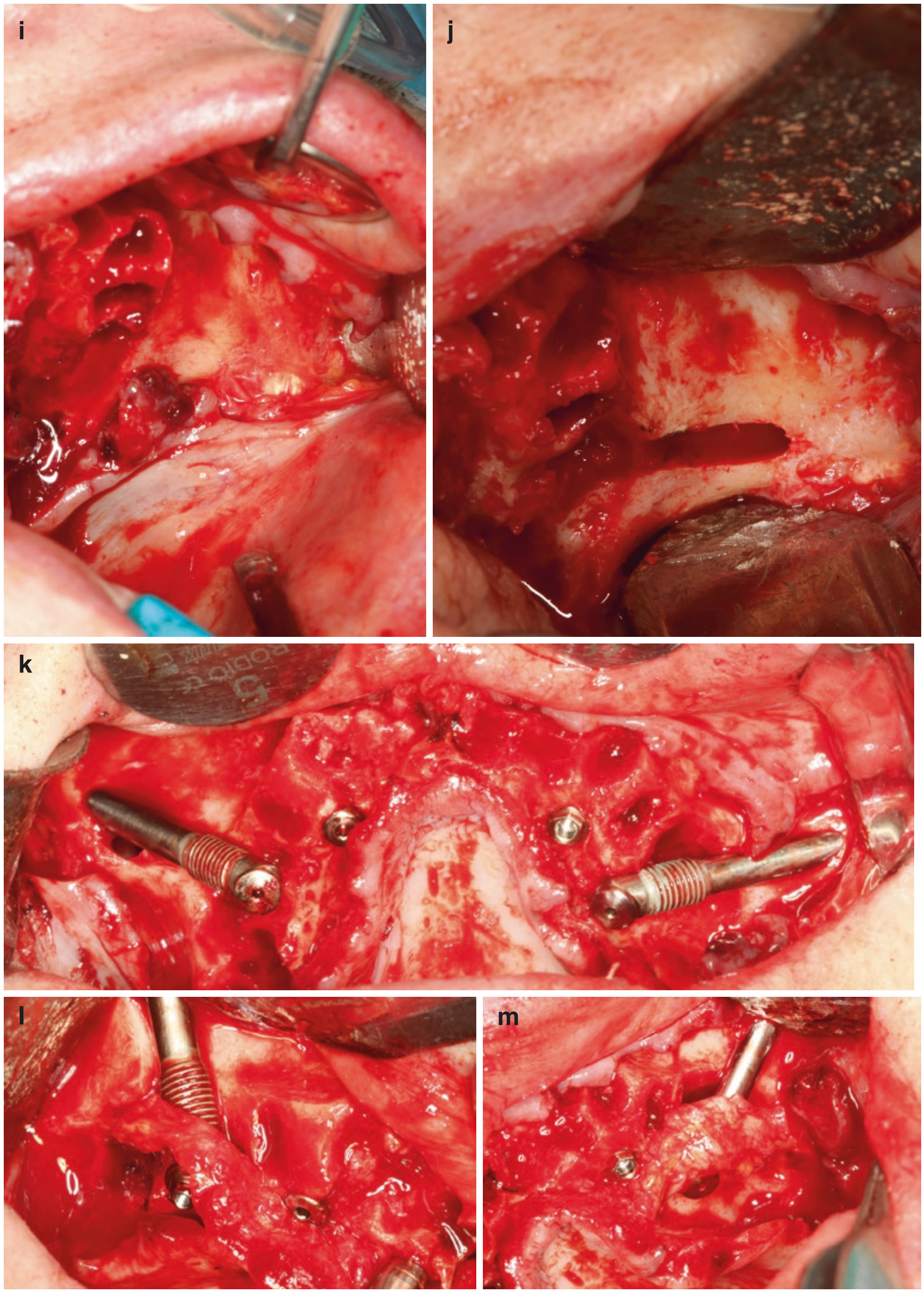

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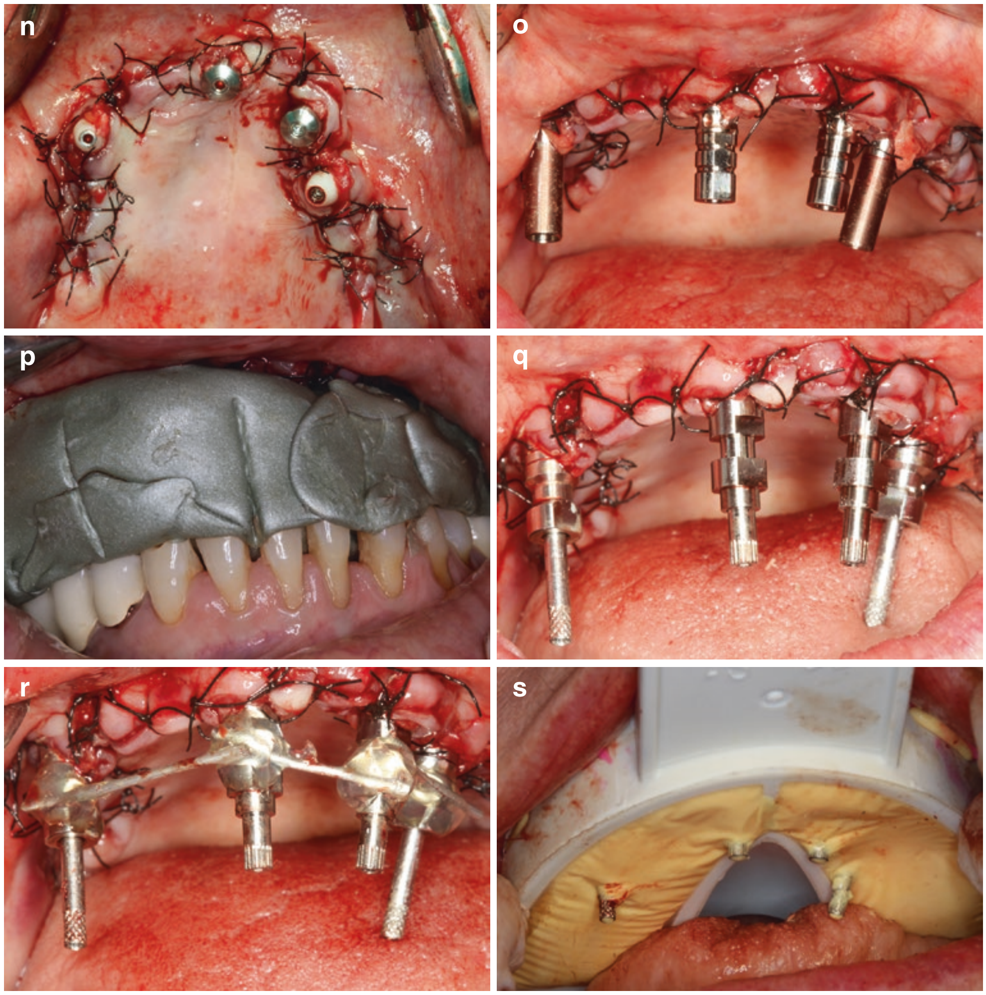

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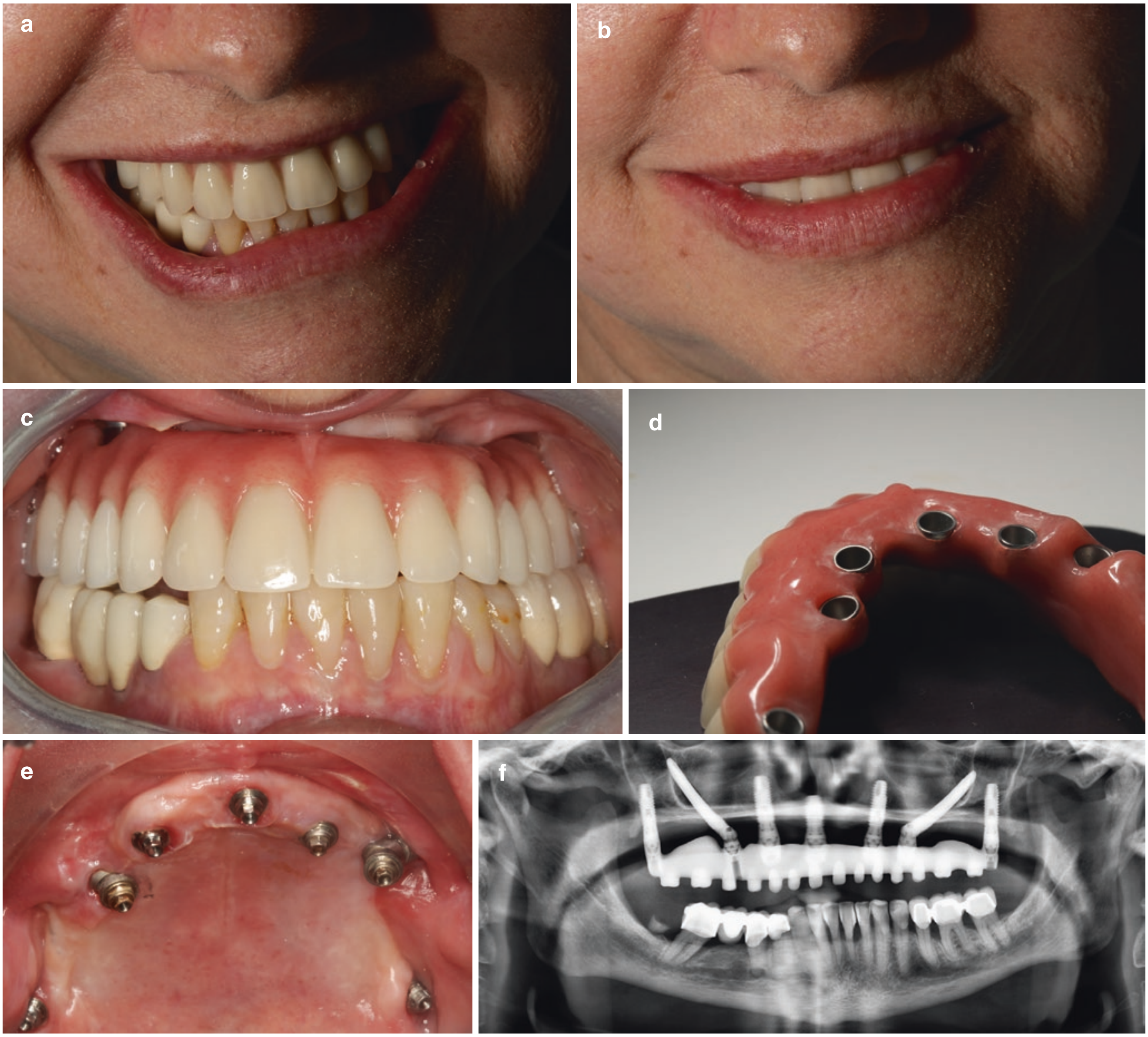


Fig. 10 (**a** and **b**) Extraoral aspect of the definitive prosthesis. (**c**) Intraoral aspect of the definitive prosthesis. (**d**) Detail of the flat surface of the definitive prosthesis. (**e**) Aspect of peri-implant soft tissues at prosthesis delivery. (**f**) Panoramic x-ray with definitive restoration in place. See the perfect fit of the structure to the prosthetic abutments (Phibo TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain)

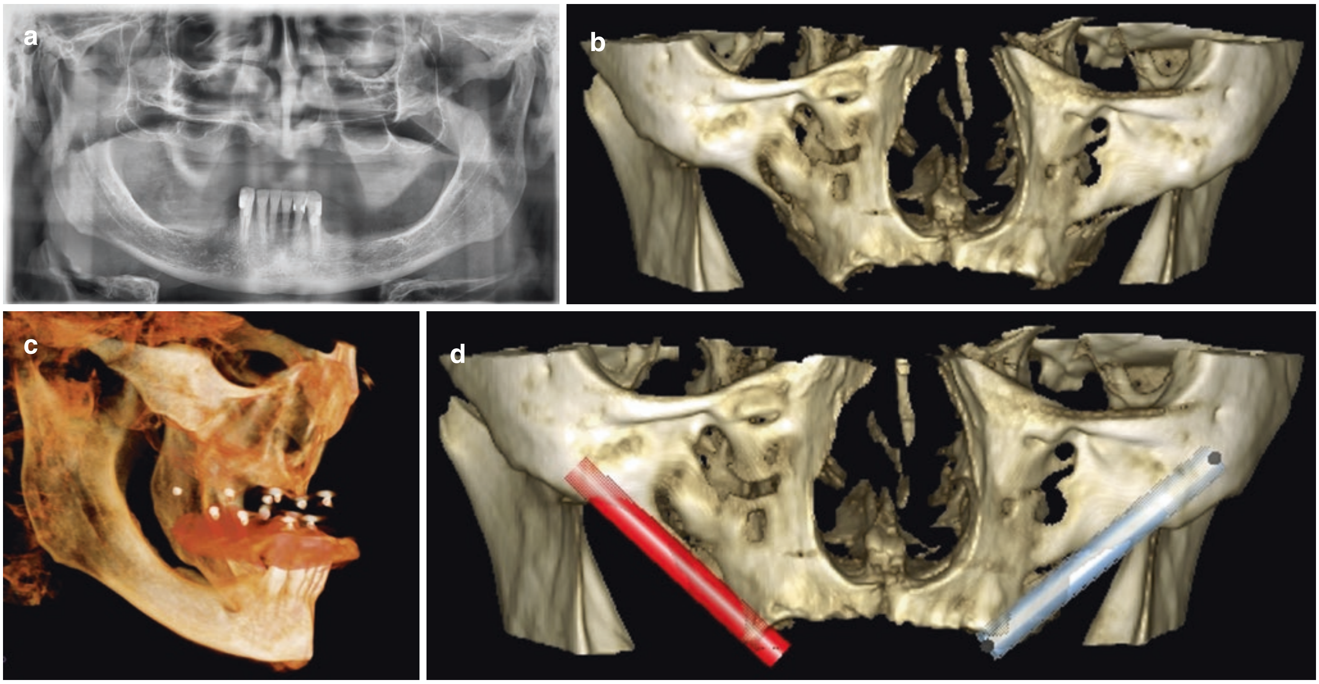


Fig. 11 Initial patient situation. (**a**) Initial panoramic x-ray showing full edentulism of the upper jaw with a severe bone atrophy and pneumatization of maxillary sinus. (**b** and **c**) In the CBCT 3D reconstruction is possible to see the absence of bone in the premaxilla. (**d**) Two zygoma implants and two anterior implants in the frontomaxillary region were planned for this patient, associated with an immediate loading protocol

Migliorança et al. (2008) due to the use of two different implant types: regular implants anchored in the maxilla and zygomatic implants anchored in the zygoma bone.

For the all-on-four hybrid, we can use the following combinations depending on the anatomy of the patient:

- One zygomatic implant, one posterior regular tilted implant and two anterior regular axial implants
- Two zygomatic implants with two anterior regular axial implants
- Three zygomatic implants with one anterior regular axial implant

From a biomechanical point of view, this technique is very similar to the all-on-four standard technique, not being necessary the use of more than four implants to support a complete full-arch rehabilitation.

The use of immediate loading follows the aforementioned protocols for the all-on-four standard concept, being necessary a minimum of 35–40 Ncm in each implant.

Figures 1, 2, 3, 4, 5, 6, 7, 11, 12, and 13 show three cases rehabilitated with this approach.

All-on-Four Zygoma or Quad Zygoma

The all-on-four zygoma or quad zygoma protocol consists in the use of four zygomatic implants, anchored in the zygoma bone, to support a full-arch maxillary rehabilitation. It was first described by Duarte et al. (2007) and is indicated when only the basal bone of the maxilla is present—no bone in zones 1, 2, and 3—so there is no possibility of regular implant insertion. It is a rescue procedure when regular implants have failed, leading to a situation of extreme bone atrophy, and when bone grafting has failed if bone grafting had been the first choice of treatment (Malevez 2012).

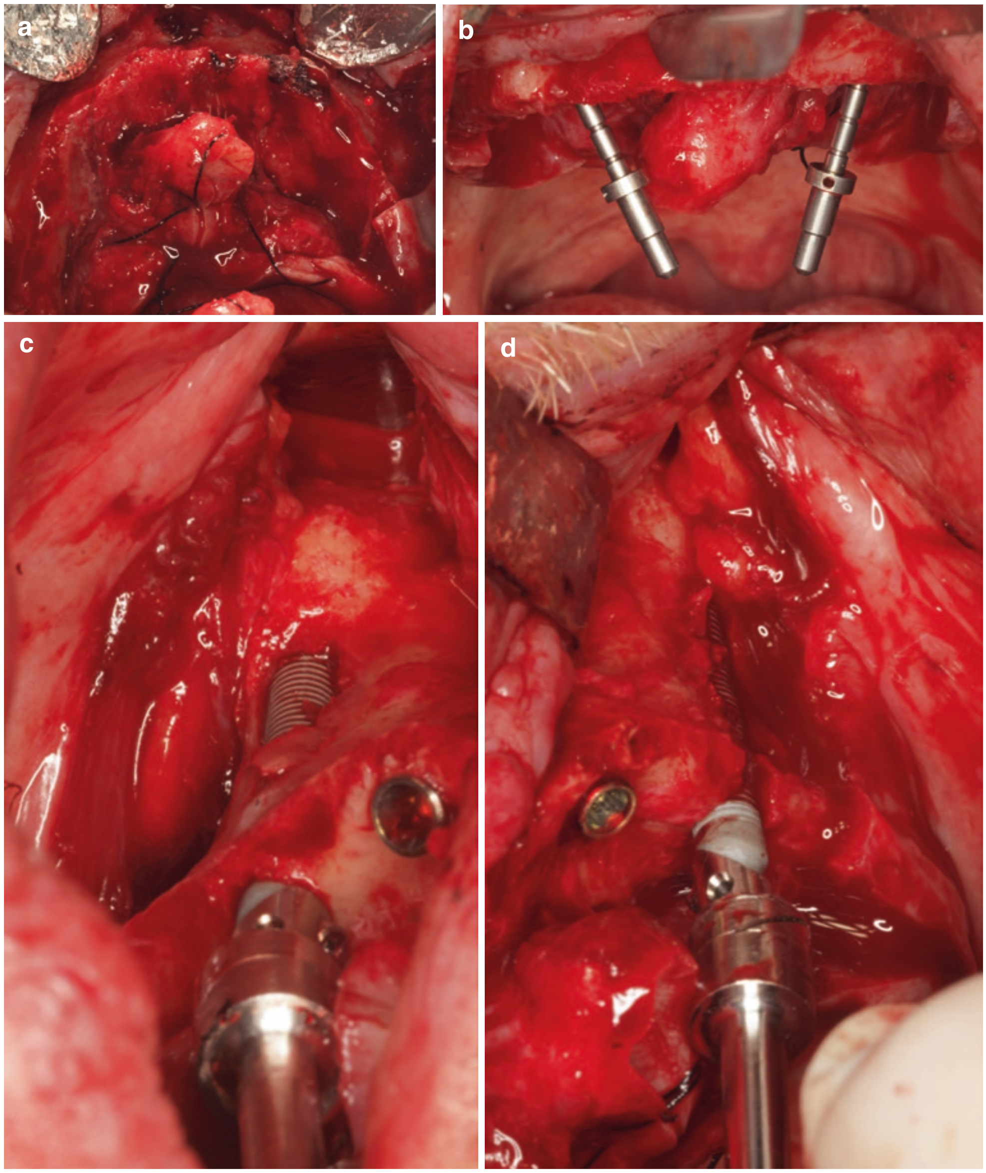
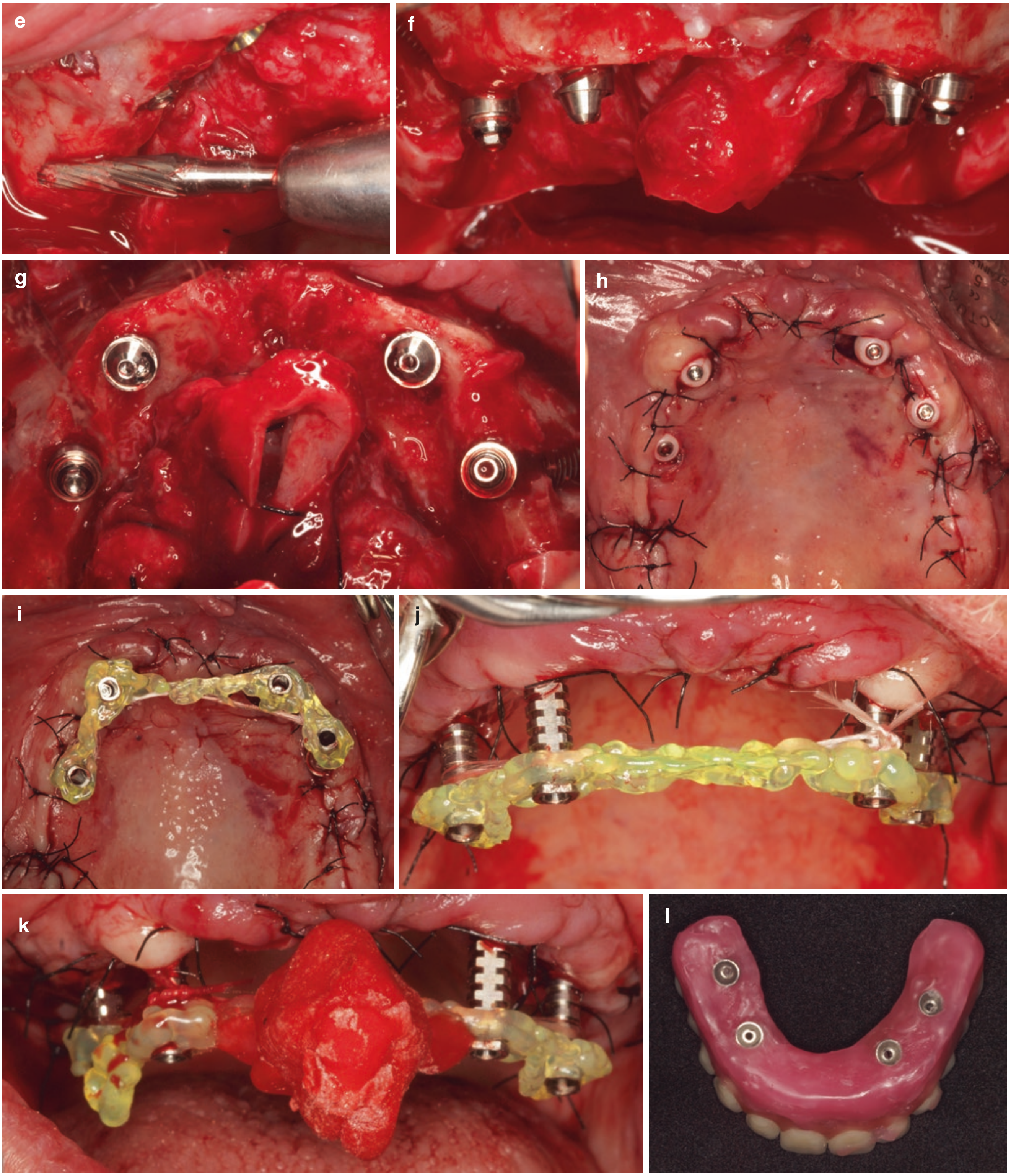


Fig. 12 Surgery and immediate loading. (**a**) Full-thickness flap elevation. (**b**) Implant bed preparation of the two anterior frontomaxillary implants. See the angulation of the preparation, to save the nasal cavity and reaching the frontomaxillary buttress. The preparation is slightly palatinized to maintain a thick buccal bone around implants (Nobel Parallel™, Nobel Biocare, Gotheborg, Sweden). (**c** and **d**) Zygoma implant placement (Branemårk System™ Zygoma, Nobel Biocare, Gotheborg, Sweden). (**e**) Ostectomy with bur to flattened the alveolar. (**f** and **g**) Aspect of the four implants with the prosthetic abutments. (**h**) Flap suture. (**i–k**) Temporary titanium abutments were placed and splinted. A bite register was done to measure vertical dimension of occlusion (VDO) and sent to the dental technician. (**l–o**) The prosthesis base was modeled directly in the mouth of the patient with wax to create a flat surface. The VDO and the occlusion were checked. (**p** and **q**) Final temporary prosthesis in resin sent by the dental technician. (**r–u**) Intraoral aspect of the temporary prosthesis. (**v**) Postoperative panoramic x-ray



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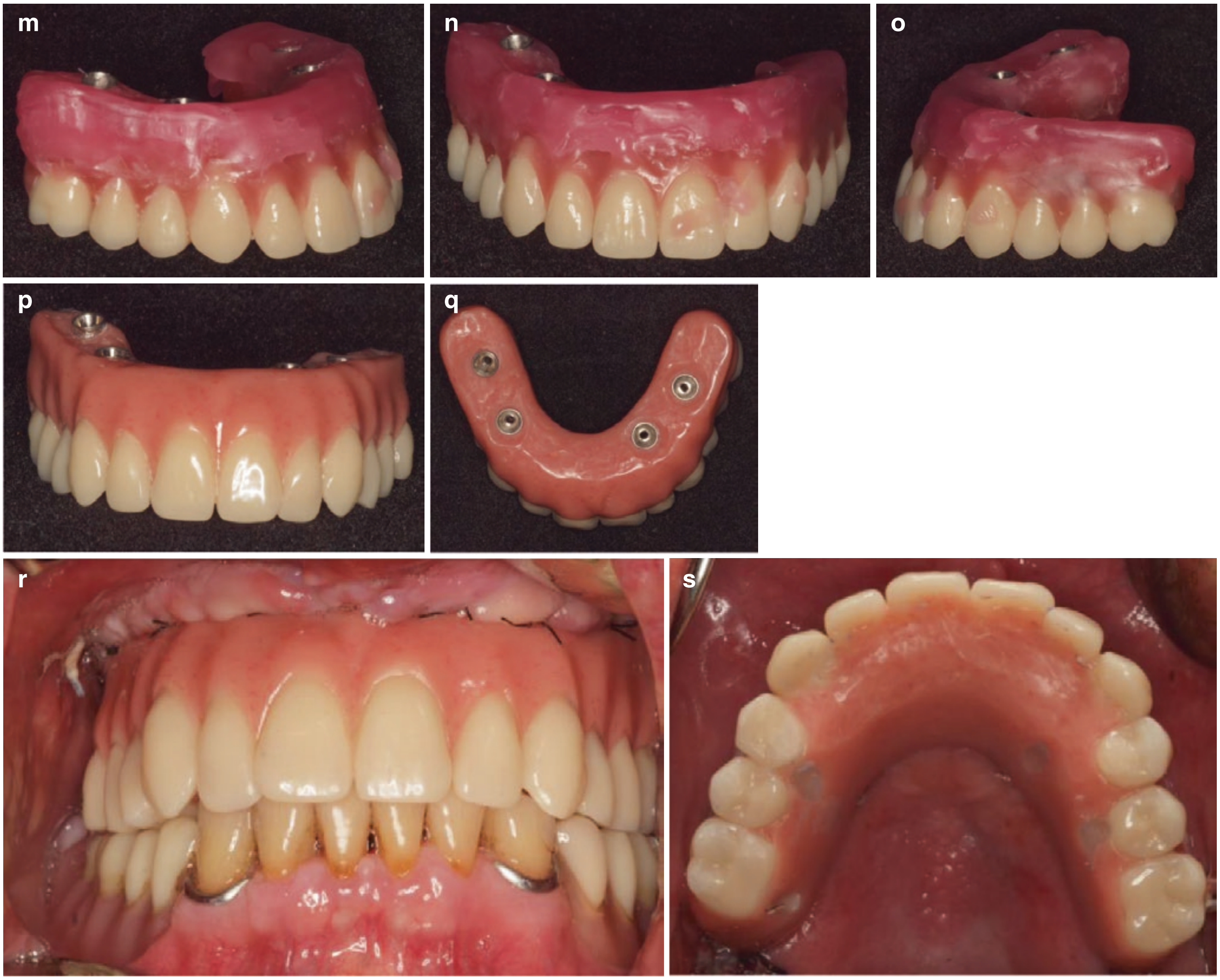

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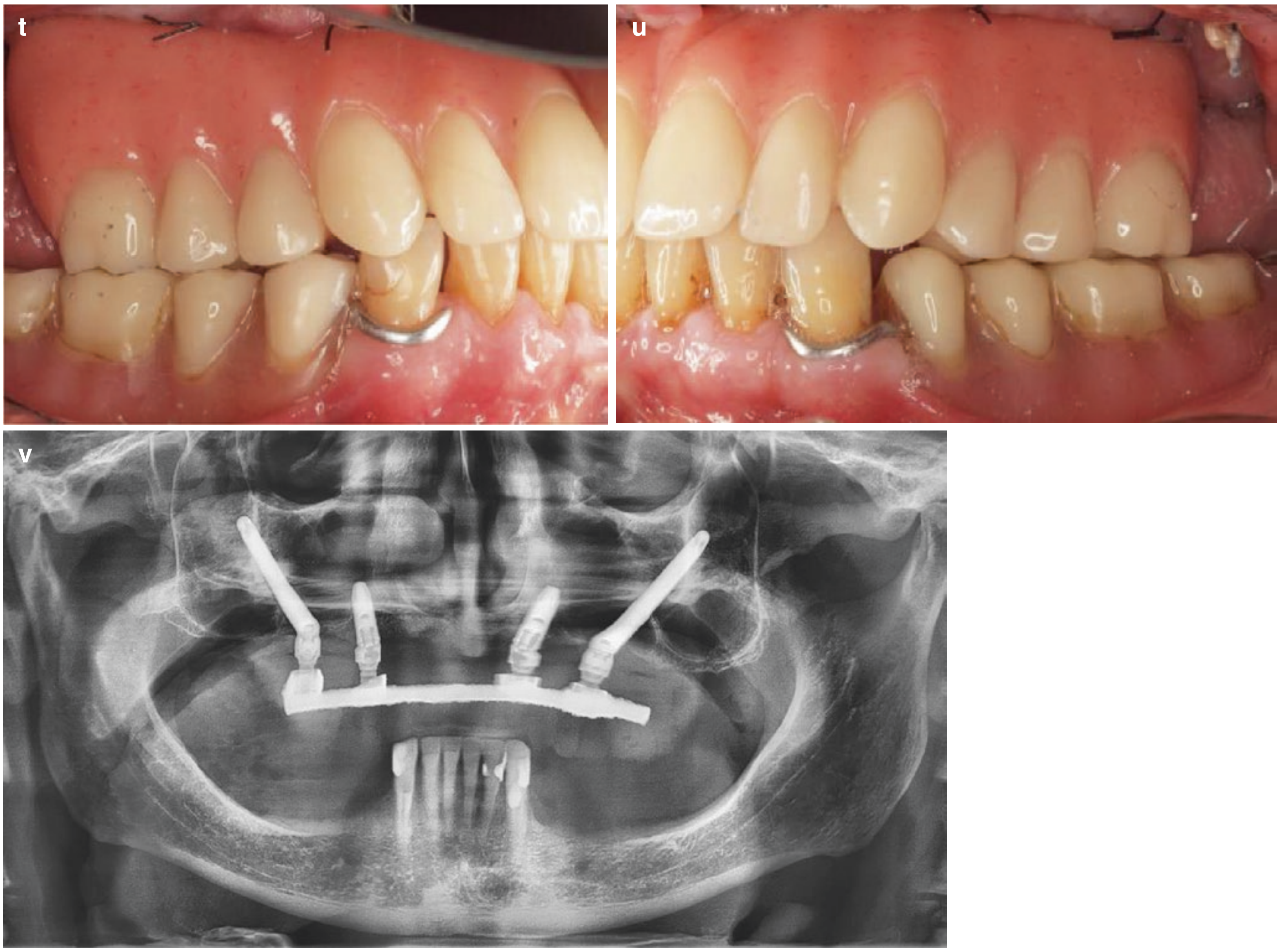

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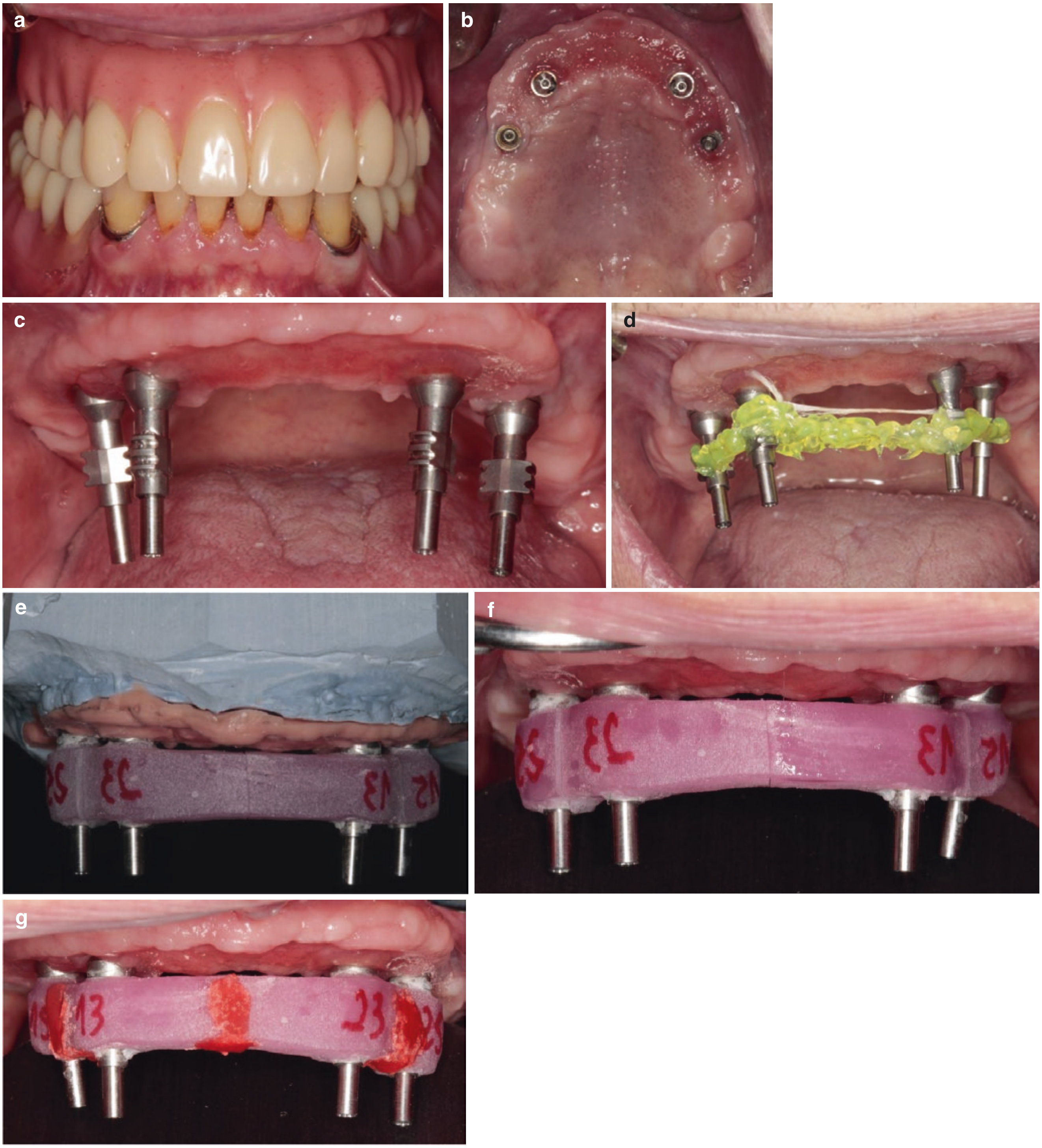
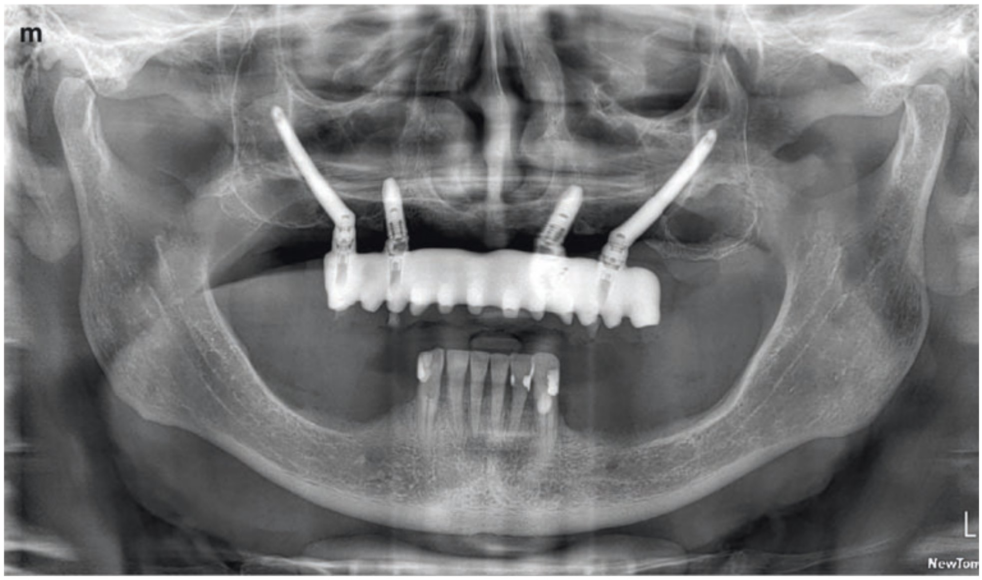


Fig. 13 Definitive prosthetic rehabilitation. (**a**) Temporary prosthesis at 4 months of control. (**b** and **c**) Aspect of soft tissues at definitive impressions at 4 months. See how with the flat shape of the temporary prosthesis it is possible to model the peri-implant tissues, avoiding food impactation and improving the oral hygiene of the patient. (**d**) Impression abutments splinted prior to take definitive impression. (**e**–**g**) Verification guide sent by the dental technician to ensure passive fit of the metal framework. The impression abutments were splinted with resin, and three cuts were done to divide the structure in four stretches. The verification guide was screwed to prosthetic abutments, and the adjustment was checked by x-rays. After this, the stretches were splinted with hard resin, and a new impression was taken. (**h** and **i**) Trial of the metal framework. (**j**–**l**) Definitive metal-resin hybrid prosthesis, detail, and intraoral aspect. (**m**) Final panoramic x-ray at definitive prosthesis delivery

Fig. 13 (continued)



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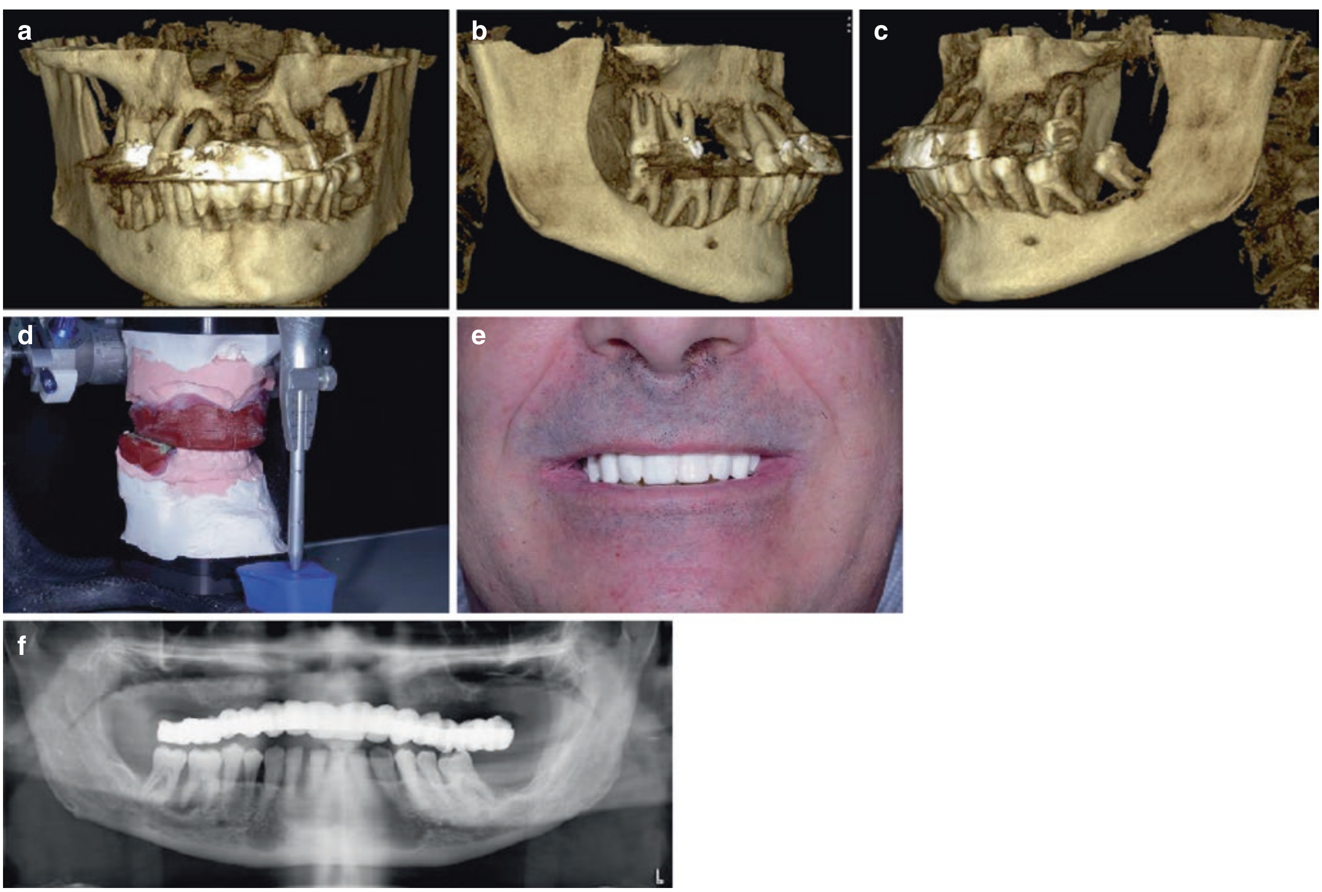

Fig. 14 (**a**–**c**) Initial CBCT of the patient showing a severe periodontitis, with impossible prognosis of the upper teeth. The treatment consists in the extraction of all the maxillary teeth and the rehabilitation with a fixed implant prosthesis. (**d**) After the extraction of the teeth with bad prognosis, the VDO was registered, and a mock-up with barium teeth, which also serves as radiographic guide, was done. (**e**) The esthetic aspect of the teeth and the occlusion were checked with the mock-up; likewise the loss of hard and soft tissues was evaluated. (**f**) With the radiographic guide, a new panoramic x-ray and CBCT were done

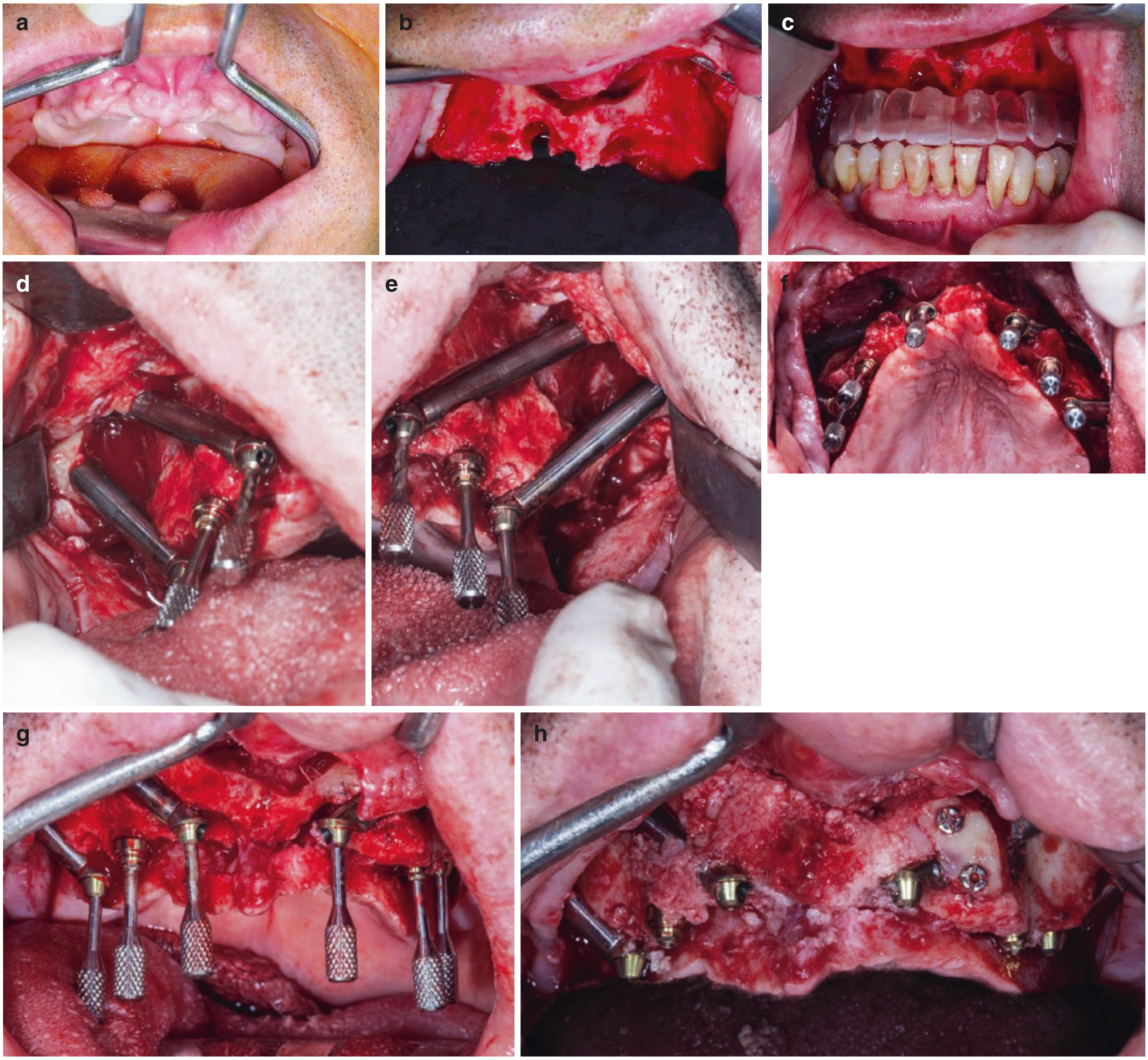

Fig. 15 Surgery. (**a**) Initial patient situation after 2 months of teeth extractions. (**b**) Full-thickness flap elevation. (**c**) Detail of the surgical guide. (**d**) Placement of two zygoma implants and a frontomaxillary implant on the right maxilla. The zygoma implants were placed with the exteriorized approach. (**e**) Placement of the zygoma implants of the left side with the exteriorized approach. A frontomaxillary implant was placed too (Galimplant® Dental Implant System, Sarria, Lugo, Spain). (**f**) Occlusal view of the implants in place. (**g**) Intraoral frontal aspect of the four zygoma implants and the two frontomaxillary implants. (**h**) Bone reconstruction of the anterior premaxilla with autogenous bone blocks and particles to improve the lip support and regenerate the bone around implant necks. (**i**–**n**) Postoperative CBCT. See that the fronto-maxillary implants pass palatally the anterior zygoma implants (Noris Medical, Nesher, Israel)

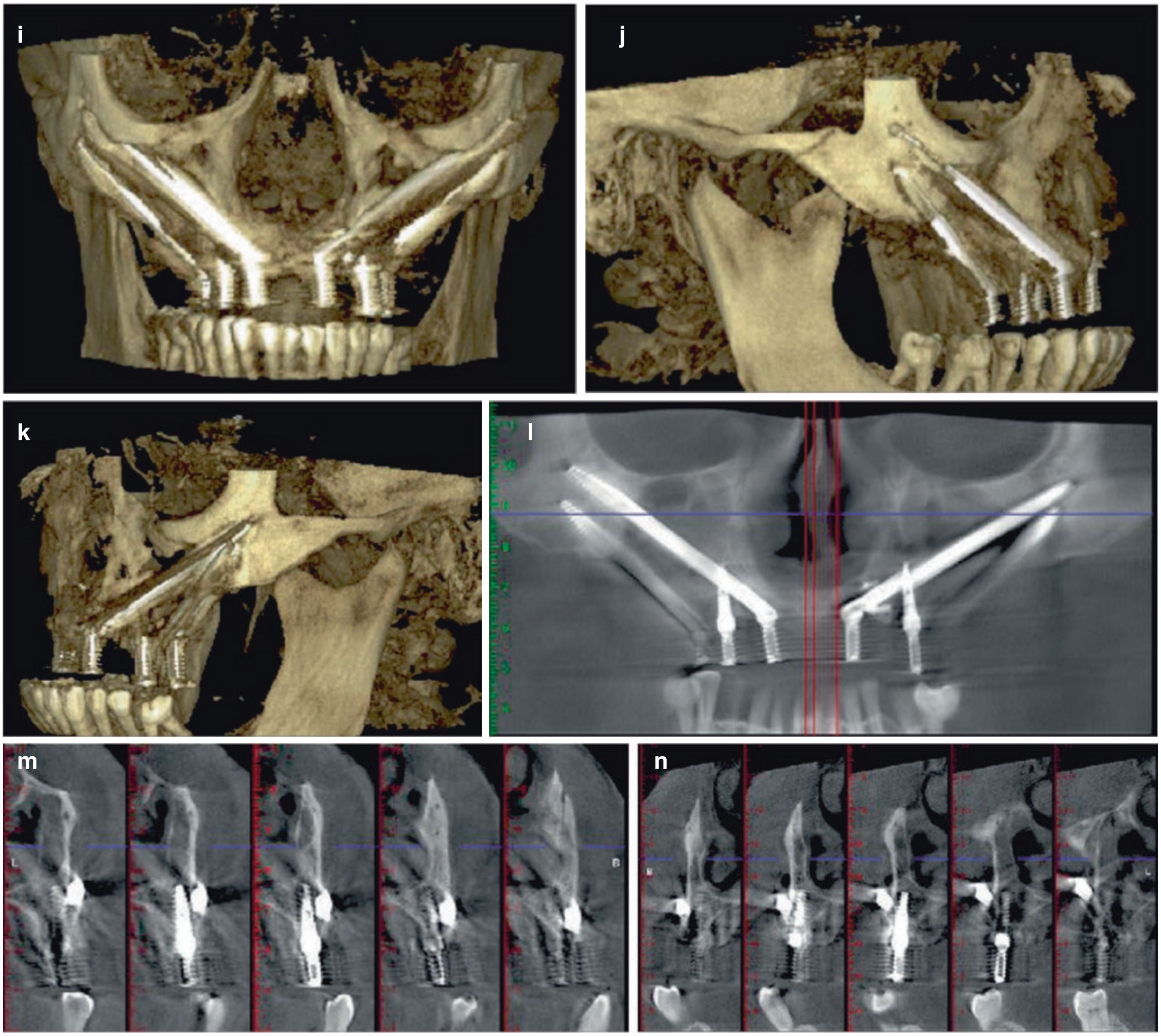

Fig. 15 (continued)

The insertion technique is the same as when a single zygomatic implant is inserted. It is suggested that the anterior implant must be inserted first in order to avoid the infraorbital nerve, and then the posterior implant is placed. The anterior zygomatic implant should emerge at the level of the lateral incisor and the posterior one at the level of the second premolar.

If zygomatic implants achieve enough insertion torque (35–40 Ncm), an immediate loading protocol is recommended, because immediate stabilization of the four implants is achieved by splinting to a rigid prosthesis. The prosthetic protocol follows the aforementioned for all-on-four standard (chapter "Immediate Loading in All-on-Four") and all-on-four hybrid protocols. Figures 14, 15, and 16 show one case rehabilitated with this approach.

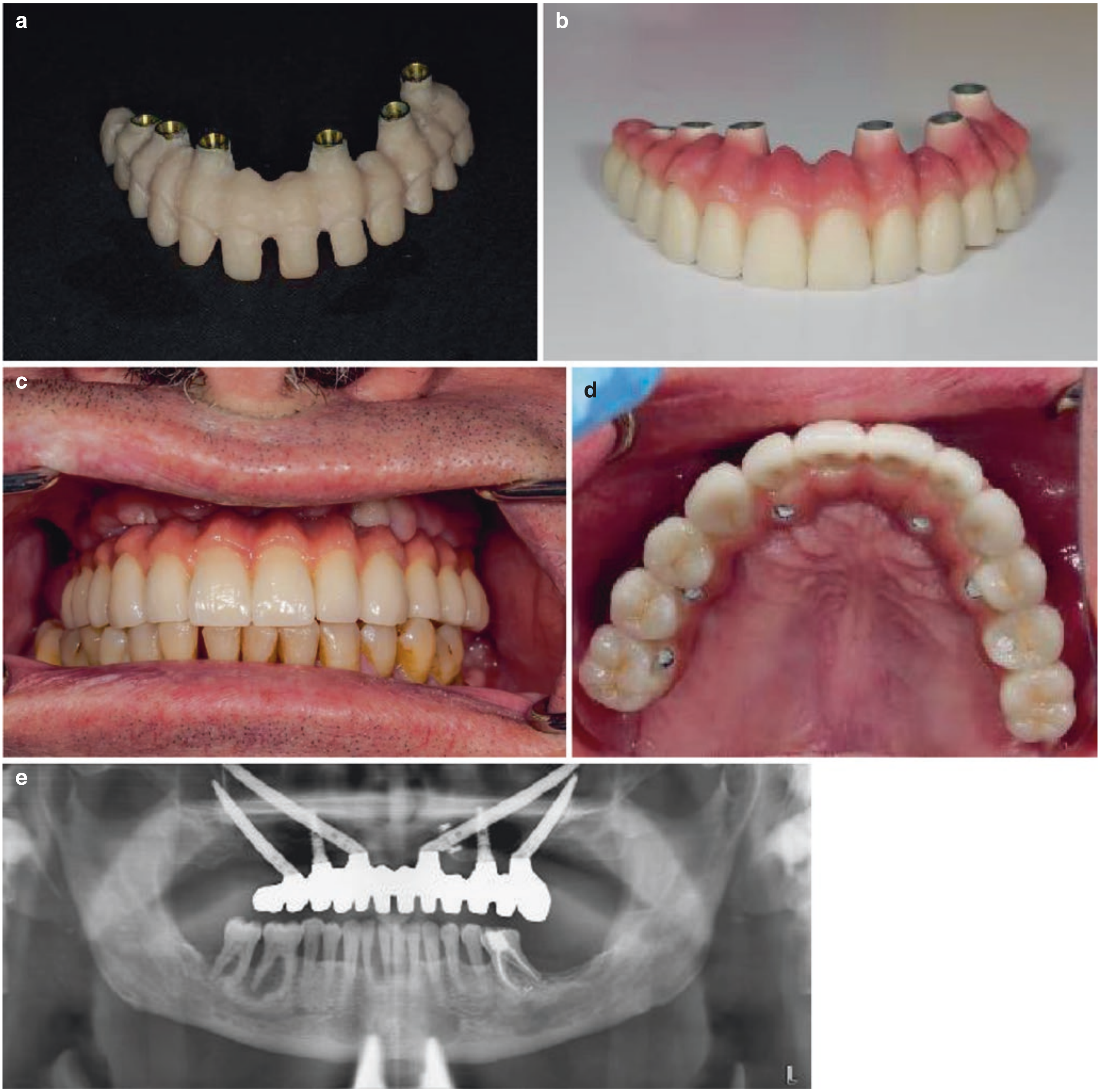

Fig. 16 Definitive prosthetic rehabilitation. (**a**) Zirconia framework. (**b**) Detail of the definitive zirconia-ceramic prosthesis. (**c** and **d**) Aspect of the definitive rehabilitation, frontal and occlusal view. (**e**) Final panoramic x-ray at prosthesis delivery

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Immediate Loading in All-on-Four

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Take-Home Messages

- The all-on-four treatment concept is a predictable option for edentulous patients or those with a failing dentition, showing implant survival rates of 93.8–100% up to 10 years.
- In the maxilla bone, availability in the premaxilla and the premolar area is necessary to achieve enough anterior-posterior distribution of the implants and reduce cantilever length.
- In mandibles this is the treatment of choice when no bone is available distal to the mental foramen.
- This approach avoids the need for extensive bone grafts and their possible complications and with the immediate loading protocol achieves an important reduction in treatment costs and overall time.

Introduction

Tooth loss gives rise to gradual resorption of the alveolar process, with a change in bone and muscle relations and in facial morphology (Sutton et al. 2004). While most of this resorption occurs in the first year after tooth loss, it continues throughout life and can often give rise to severe bone atrophy both vertically and in width (Rossetti et al. 2010). Severe bone atrophy of the upper maxilla (Cawood and Howell class V and VI) is associated with certain problems such as reduced perioral tissue support, the impossibility of wearing complete dentures, chewing and speech alterations, and difficulties in placing dental implants due to the limited amount of available bone (Cawood and Howell 1988).

Many surgical techniques have been proposed for the rehabilitation of this type of patients. These methods can be classified into bone grafting techniques [i.e., guided bone regeneration (Urban et al. 2017), sinus floor augmentation (Wallace and Froum 2003; Pjetursson et al. 2008), onlay grafting with autogenous bone blocks (Sbordone et al. 2009; Aloy-Prósper et al. 2015), and inlay autogenous bone grafting (Nyström et al. 2009)], distraction osteogenesis (Jensen et al. 2011)], crestal expansion techniques [i.e., split crest (Jensen et al. 2009)], the use of special implants [i.e., short dental implants (<6 mm) or narrow dental implants (<3 mm) (Felice et al. 2011)], and the modification of the original implant insertion protocol to avoid bone grafting by using areas of residual bone or anatomical buttresses [i.e., zygomatic implants (Branemark et al. 2004; Araújo et al. 2017), pterygoid implants (Candel et al. 2012), implant insertion in the maxillary tuberosity (Lopes et al. 2015), tilted implants (Testori et al. 2017), palatal implants (Peñarrocha et al. 2009; Peñarrocha-Oltra et al. 2013), and implants placed in the nasopalatine canal (Peñarrocha et al. 2014)].

The use of bone grafting to allow implant placement in atrophic maxillae is associated with more frequent complications and higher morbidity, especially when an extraoral donor site is required (Nkenke and Neukam 2014). The associated increase in economic costs and a longer treatment time can lead, sometimes, to limit patient acceptance to treatment. Additionally, the use of extraoral grafts (i.e., iliac crest) has a non-predictable resorption pattern that can be of almost the entire graft, especially in the edentulous maxilla (Sbordone et al. 2012). The use of short and narrow implants is a promising alternative concept for the treatment of atrophic maxilla, but the lack of trials for this specific situation with follow-ups of at least 5 years advises to take this result with caution (Esposito et al. 2015).

The use of anatomical buttresses and the residual bone is a predictable way to rehabilitate the atrophic maxilla with

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dental implants and fixed full-arch prostheses and several studies available for these techniques (Alzoubi et al. 2017a; Busenlechner et al. 2016a, b; Candel-Marti et al. 2015a; Fortin 2017; Maló et al. 2005; Peñarrocha et al. 2012). This approach avoids complications and morbidity associated with bone graft and reduces treatment cost and time and in overall has a high patient satisfaction (Candel-Marti et al. 2015b; Alzoubi et al. 2017b).

Rationale for Immediate Loading of Atrophic Jaws

Reduction treatment time is a goal in modern implant dentistry. Increasingly, patients' expectations go through a reduction between implant placement and the recovery of the function and esthetics with the installation of prosthesis as soon as possible (De Bruyn et al. 2014). Additionally, the adaptation to removable prosthesis is difficult, especially in elderly, what it entails and increasing demand of fixed prosthesis (Allen and McMillan 2003). The efforts then must be placed to provide immediate loading prosthesis especially in fully edentulous patients that are the ones with more problems to adapt to traditional dentures, and the treatment is very important to recover their function and social life (Muller et al. 2007).

The All-on-Four Treatment Concept

The "all-on-four" treatment concept was developed to maximize the use of available remnant bone in atrophic jaws, allowing immediate function and avoiding regenerative procedures that increase the treatment costs and patient morbidity, as well as the complications inherent to these procedures (Soto-Peñaloza et al. 2017).

Biomechanics of the All-on-Four Treatment Concept

The protocol uses four implants in the anterior part of complete edentulous jaws to support a provisional, fixed, and immediately loaded prosthesis. The two most anterior implants are placed axially, whereas the two posterior implants are placed distally and angled to minimize the cantilever length and to allow the application of prostheses with up to 12 teeth, thereby enhancing masticatory efficiency (Maló et al. 2003a, b) (Fig. 1a, b).

Several clinical studies have reported that tilting the implants represents a feasible treatment option (Krekmanov 2000; Krekmanov et al. 2000; Aparicio et al. 2001; Fortin et al. 2002; Maló et al. 2003a, 2005; Calandriello and Tomatis 2005; Capelli et al. 2007; Agliardi et al. 2008, 2009; Peñarrocha et al. 2010). Such technique is related to several surgical and prosthetic advantages, like the possibility of placing long implants with improvement of bone anchorage, the reduction of the need for bone grafting, the avoidance of long cantilevers, and the possibility of increasing the distance between anterior and posterior abutments, with improvement of the load distribution. Additionally, no difference in the marginal bone loss between tilted and axially placed implants, placed in either jaw, has been reported, suggesting that tilting of the implants causes no detrimental effect on the osseointegration process (Krekmanov 2000; Aparicio et al. 2001; Capelli et al. 2007; Koutouzis and Wennström 2007; Agliardi et al. 2009). A high degree of patient satisfaction was also reported as related to this clinical procedure (Capelli et al. 2007; Testori et al. 2008; Agliardi et al. 2009).

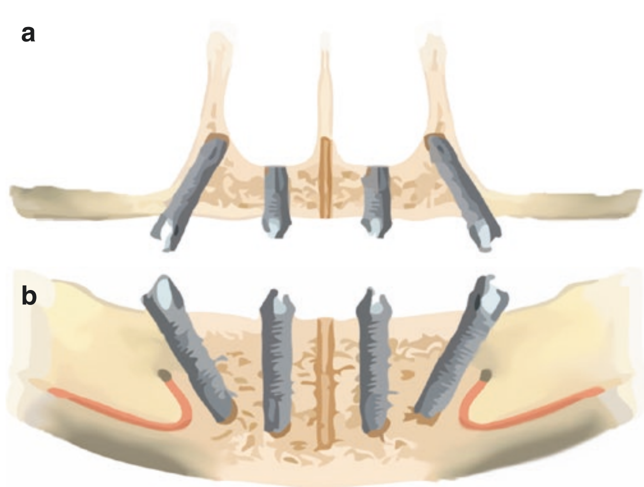

Fig. 1 Schematic view of the all-on-four treatment concept. The distal implants were tilted to save the maxillary sinus (**a**) and the mental foramen and the anterior loop of the alveolar inferior nerve (**b**). This technique avoids the use of reconstructive surgeries and increases the anterior-posterior (AP) spread of the implants

Branemark et al. in 1995 was the first who advocated for the use of a reduced number of implants in the treatment of edentulous patients (Branemark et al. 1995). This long-term study with a 10-year follow-up concluded that the use of only four implants is enough both in the maxilla and mandible recommending avoiding the use of graft techniques (i.e., sinus augmentation) for the installation of more implants. From a biomechanical point of view, the rationale for the use of only four implants is that when the force is applied to the more distal part of the prosthesis, the 90% of the strength is absorbed by the more distal implants. The rest (10%) is absorbed by the two more anterior implants. The rest of the implants practically do not receive forces (Rangert et al. 1989). When six or four implants are spread out over the same arch length, there is no significant benefit in selecting six rather than four implants from a biomechanical point of view, because in this situation, the anterior and the posterior implants receive the forces with little to no contribution of the intermediate implants (Fig. 2). Additionally, tilting the posterior implants leads to more benefits as more reduce cantilever extension and a better spreading of the implants (Brunski 2014).

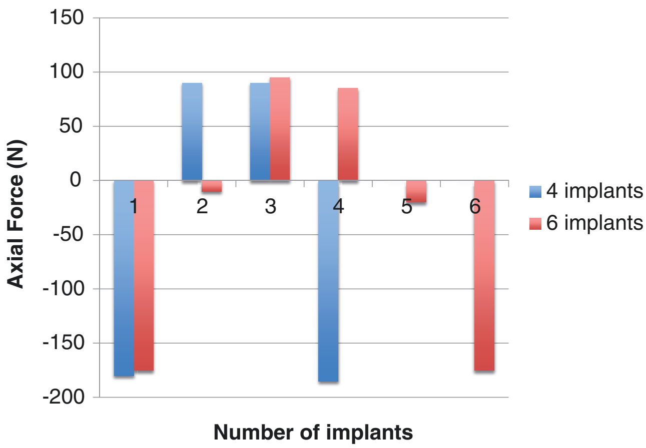

Fig. 2 Axial forces on four or six implants spread over the same arch. The intermediate implants (between the most anterior and the most posterior) practically do not receive forces. With the same arch spread, the most anterior and, principally, the most posterior implants receive most of the forces regardless of the number of implants

Prognosis of the All-on-Four Treatment Concept

In the treatment of atrophy for full-arch implant-supported restorations, it is considered that four implants are enough for immediate loading and for the final prosthesis (Penarrocha-Diago et al. 2017). Immediate loading with the all-on-four concept provides high implant survival rates in the medium to long term (see Table 1). The all-on-four treatment concept offers a predictable way to treat the atrophic jaw in patients that do not prefer regenerative procedures, which increase morbidity and the treatment fees. The results obtained in a recent systematic review that assess results of 11,743 implants indicate a survival rate of 99.8% for more than 24 months (Soto-Peñaloza et al. 2017). For this chapter we reviewed the literature, and this approach showed implant survival rates around 93.8–100% up to 10 years for both jaws, based on a sample of 11,627 implants. Regarding the jaw, an implant survival rate of 95.4–100% is expected for the mandible up to 7 years. For the maxilla, an implant

Table 1 Implant survival and prosthetic complications of immediate loading all-on-four

Author/year	Location	Patients	Implants	Follow-up (months)	SR (%)	Prosthetic complications
Capelli et al. (2007)	Both	65	342	36	97.6	NR
Francetti et al. (2008)	Mandible	68	248	60	100	Prosthesis fracture 7/68
Agliardi et al. (2010)	Both	173	692	60	98	Prosthesis fracture 24/173
Butura et al. (2011)	Mandible	219	857	36	99.6	No
Maló et al. (2011)	Both	245	980	120	93.8	Screw loosening 12/245 Prosthetic teeth wear 1/245
Cavalli et al. (2012)	Maxilla	34	136	12–73	100	Prosthetic teeth fracture temporary 20.6% definitive 17.7%
Crespi et al. (2012)	Both	36	176	36	98.2	No
Francetti et al. (2012)	Both	47	196	60	100	No
Maló et al. (2012)	Maxilla	242	968	60	98	Fracture or loosening of mechanical and prosthetic components
Babbush et al. (2013)	Both	NR	227	36	98.7	NR
Di et al. (2013)	Both	69	344	12–56	96.2	Change fixed prosthesis for overdenture 3/69
Balshi et al. (2014)	Both	152	800	60	97.5	NR
Browaeys et al. (2015)	Both	20	80	36	100	No
Lopes et al. (2015)	Both	23	92	60	96.6	Prosthesis fracture 7/23 Screw loosening 2/23
Maló et al. (2015a)	Maxilla	43	172	72	95.7	Prosthesis fracture 7/43 Screw loosening 6/43
Maló et al. (2015b)	Mandible	324	1296	84	95.4	–
Maló et al. (2015c)	Both	110	440	60	95.5	–
Babbush et al. (2016)	Both	169	856	36	99.8	No
Sannino and Barlattani (2016)	Mandible	85	340	36	98.5	No
Tallarico et al. (2016a)	Both	56	224	84	98.2	–
Tallarico et al. (2016b)	Maxilla	20	80	60	98.6	Screw loosening 2/20
Niedermaier et al. (2017)	Both	NR	2081	84	97	NR

survival rate of 95.7–100% is expected up to 6 years. Regarding technical complications the most frequent is the fracture of the prosthesis or the veneering material followed by the loosening of the screws. Di et al. (2013) of 69 edentulous jaws reported the change of three fixed prostheses for removable overdentures after the loss of one or more implants and no replacement of it.

All-on-Four Clinical Procedures

Cases 1 (Figs. 3a–e, 4a–g, 5a–j, and 6a–h), 2 (Figs. 7a–e, 8a–f, 9a–e, 10a–c, and 11a–f), 3 (Figs. 12a–i, 13a–f, 14a–e, 15a–g, and 16a–e), and 4 (Figs. 17a–g, 18a–l, 19a–g, and 20a–d) represent the clinical procedure to perform all-on-four.

Fig. 3 (**a**) Initial panoramic x-ray showing a patient with multiple teeth lost and severe periodontal disease. In the maxilla no bone is present in zone I (molars). The treatment plan consists in the rehabilitation of the patient with an all-on-four both in the maxilla and mandible. (**b**) Smile of the patient. The transition line is hidden by the lip except in the second quadrant of the maxilla. It is necessary to do an ostectomy in this area to hide the transition line. (**c**) Intraoral view of the patient showing multiple teeth lost and severe periodontal disease. The patient wants to improve her dental esthetics. (**d**) Smile dynamics of the patient. (**e**) Digital smile design simulating the new position of the teeth and their dimensions

Fig. 3 (continued)

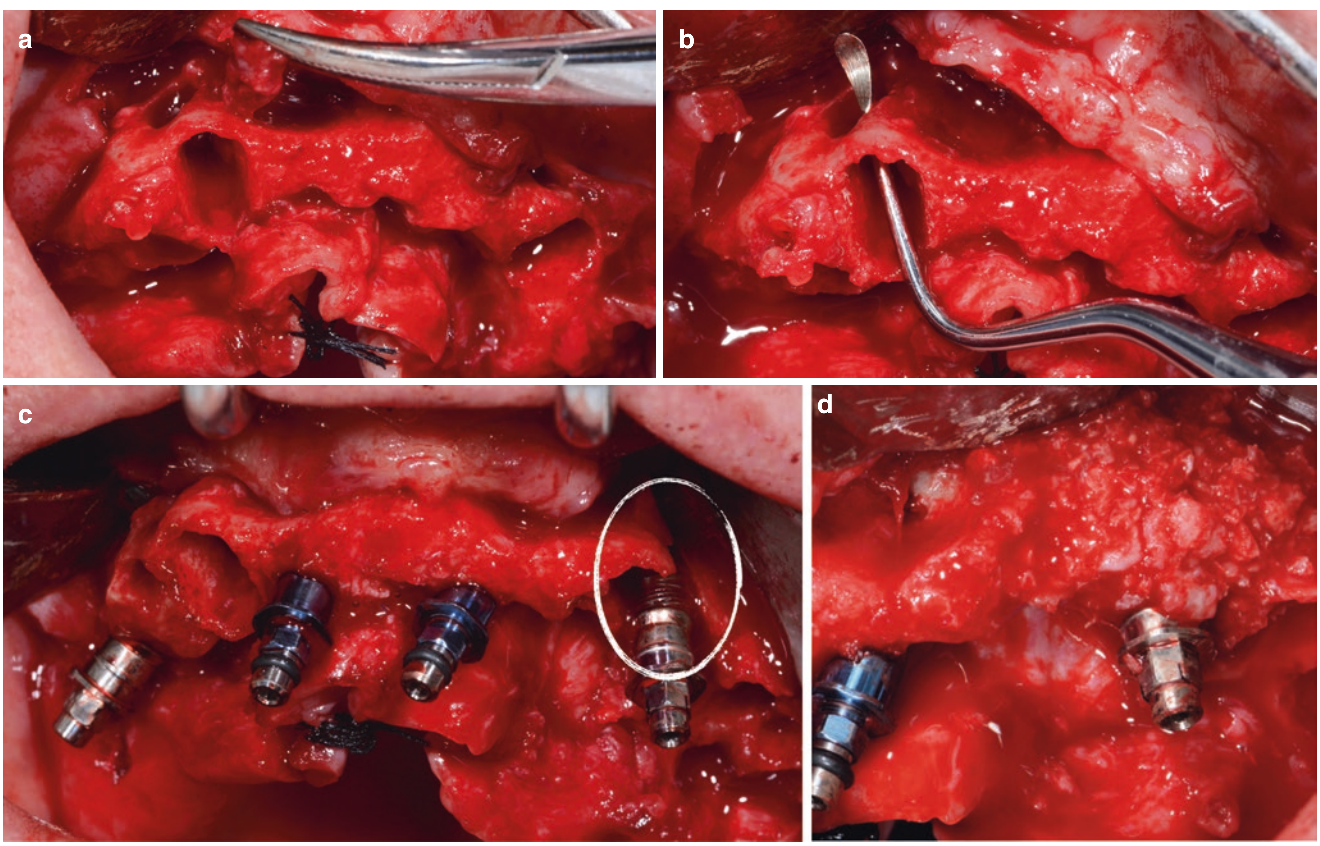

Fig. 4 Surgery of the upper maxilla. (**a**) After extraction of remnant teeth, a full-thickness flap is elevated. A mid-crestal incision is made with two vertical-releasing incisions. (**b**) Removal of all granulation tissue. In this case a bone defect is found after remove of the periapical lesion of the upper right canine. (**c**) Four implants were placed in the upper maxilla (Intraoss®, Implantes Odontológicos, São Paulo, Brasil). The left distal implant presents a bone dehiscence. All implants were placed slightly palatal. (**d**) An autogenous bone graft is placed covering the peri-implant dehiscence. (**e**) A collagen membrane is positioned over the bone graft. (**f**) Healing caps were placed before suturing of the flaps. (**g**) After suturing of the flaps, four impression abutments were placed. In this case the temporary prosthesis was made by the dental technician

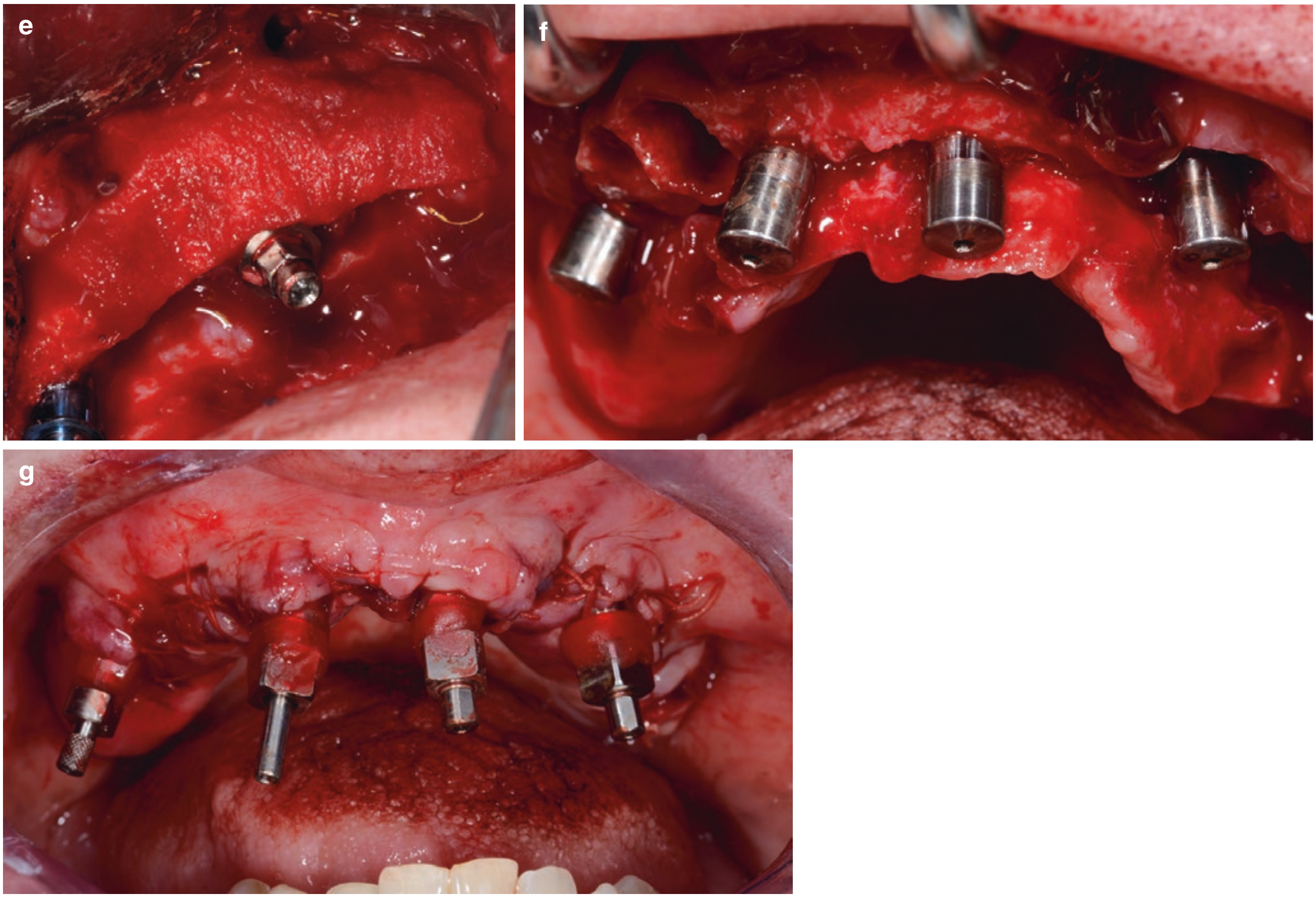

Fig. 4 (continued)

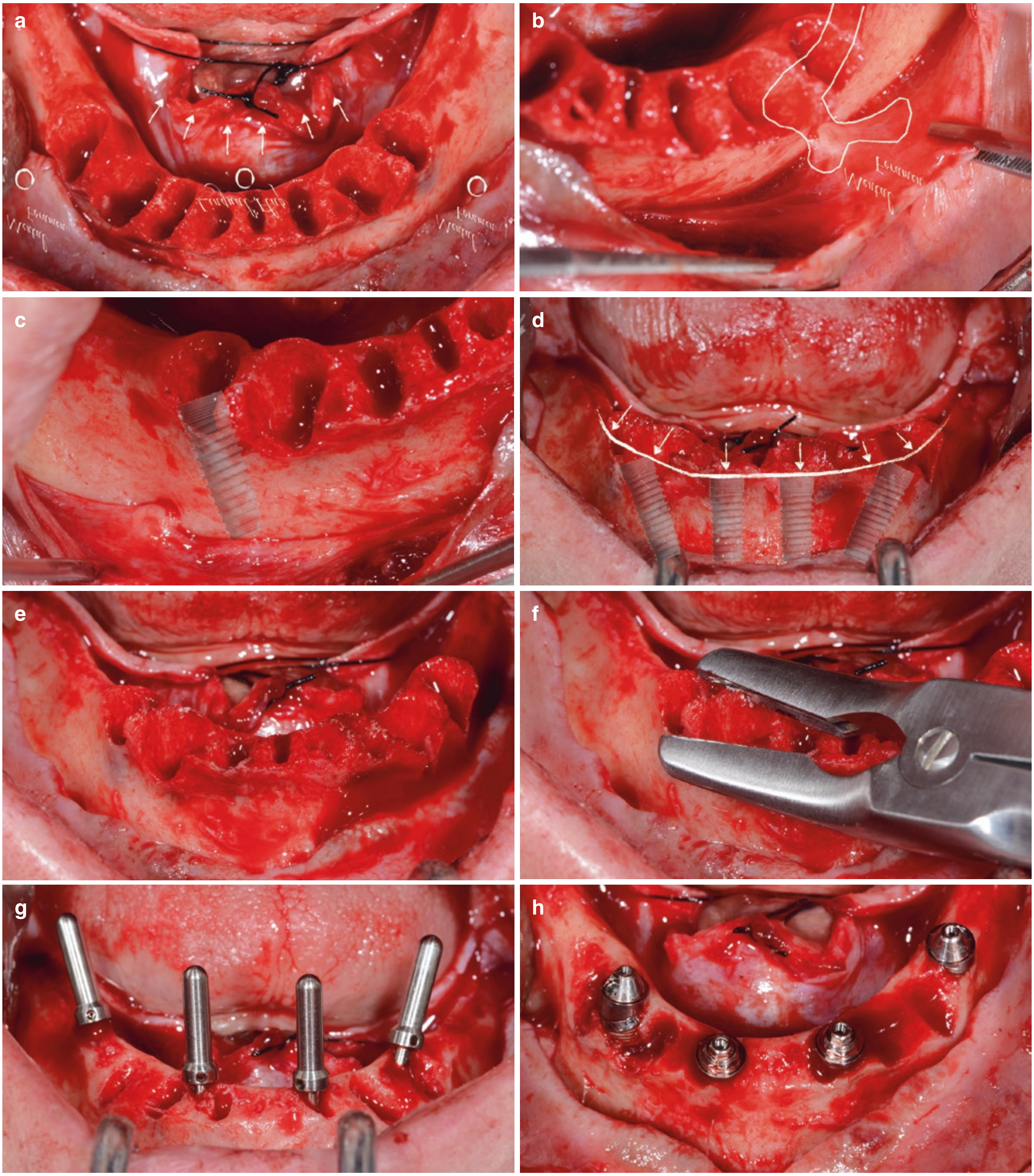

Fig. 5 Surgery of the mandible. (**a**) A full-thickness flap is elevated after teeth extractions. (**b**) In the mandible it is very important to localize the mental foramen to avoid damages and for the correct position of the distal implant. This anatomical landmark represents the distal limit for implant placement. (**c**) Schematic illustration showing the position of the distal implant in relation to mental foramen. Tilting the distal implants is possible to avoid damage to the nerve and reduce the cantilever of the prosthesis. (**d**) Simulation of the four implants placed in the mandible. (**e**) Especially in post-extractive cases, it is necessary to regularize the alveolar crest to create a flat surface. (**f**) Ostectomy with Gubia forceps. (**g**) Position of the four implants of the mandible. Two anterior straight implants and two posterior tilted implants (Intraoss®, Implantes Odontológicos, São Paulo, Brasil). (**h**) Prosthetic abutments in place. The anterior was straight and the two posterior angulated. The height of the abutments depends on the mucosa height. (**i**) Flaps sutured. (**j**) Final panoramic x-ray showing four implants placed in the maxilla and four in the mandible

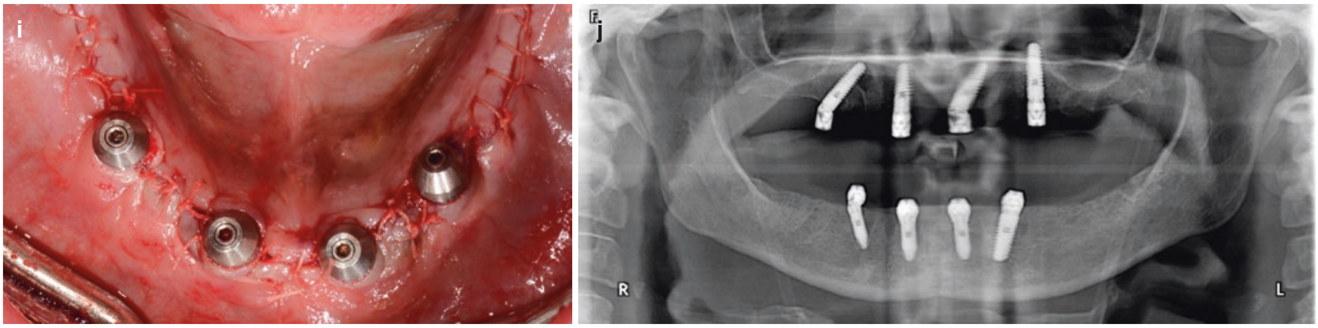

Fig. 5 (continued)

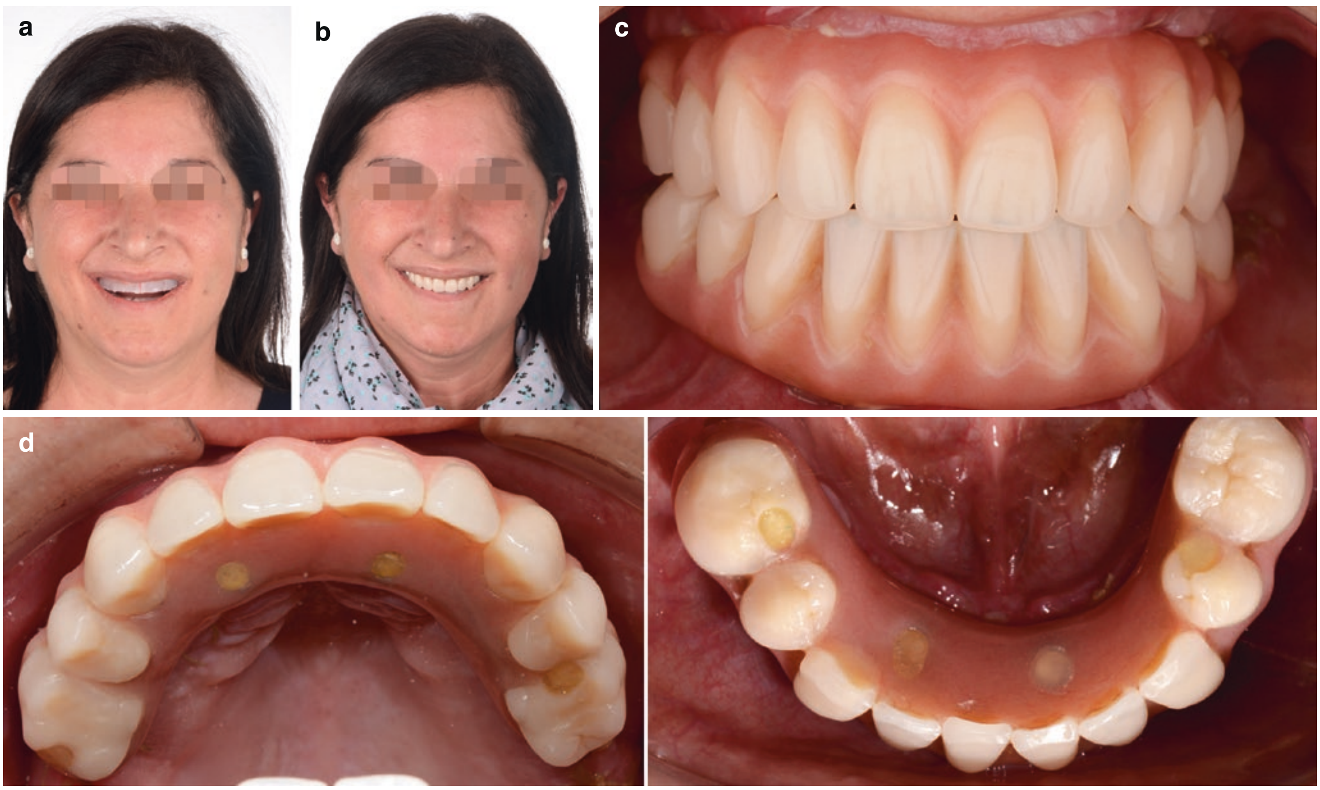

Fig. 6 Temporary prosthetic rehabilitation. (**a**) Wax bite to valorate vertical dimension of occlusion (VDO), smile line, and teeth position. (**b**) Extraoral view of the patient with the temporary rehabilitation. (**c**) Intraoral view of the temporary prosthesis in occlusion. (**d**) Occlusal view of the temporary prosthesis. (**e**) Panoramic x-ray with the temporary prosthesis. The prosthesis was splinted with a metal bar. (**f**) Frontal view of the peri-implant mucosa at 4-month control. See the adaptation of the mucosa to the flat base of the prosthesis. (**g**) Occlusal view of the upper peri-implant mucosa at 4-month control. (**h**) Occlusal view of the lower peri-implant mucosa at 4-month control

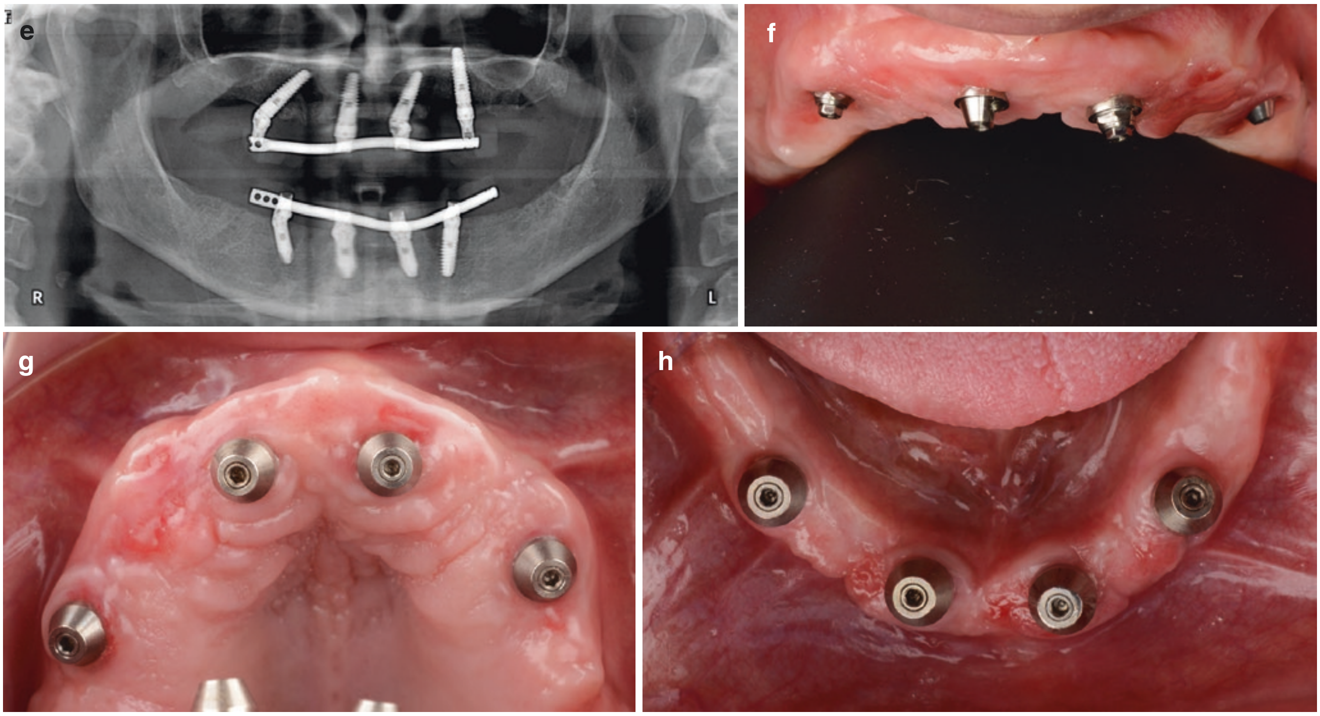

Fig. 6 (continued)

Anesthesia

Local infiltrative anesthesia is applied at the buccal or labial and the lingual or palatal sides depending on the jaw with articaine chlorhydrate with 1:100,000 epinephrine.

In the case that the patient still has remnant teeth, the first step is their extraction.

Incision

With a 15 or 15C blade, a mid-crestal incision is made from the area of the first molar of one side to the contralateral first molar. Vertical-releasing incisions are made at the level of the first molars. In cases with little keratinized mucosa, the incision can be displaced slightly palatal or lingual to enhance the tissue in the buccal aspect. In cases with very little or no keratinized tissue, especially in the mandible, a connective tissue graft or free gingival graft, prior to definitive restoration, will be necessary to ensure comfort for the patient and to facilitate oral hygiene procedures.

Flap Elevation

A mucoperiosteal flap is elevated to expose the alveolar bone. In the mandible it is easier to start elevating the lingual flap because it is less firmly attached to the underlying bone. In the maxilla it is easier to start with the buccal flap for the same reason.

The key objective during flap elevation is to localize the mental foramina in the mandible and the anterior wall of the maxillary sinus, because these represent the posterior anatomical limits for the distal implants in this technique. Studying the preoperative CBCT can facilitate this by taking into account some anatomical references.

Evaluation of Anatomical Limits

It is very important to determine the trajectory of the inferior alveolar canal and determine if it follows a mesial loop before emerging through the mental foramen or not. Studying carefully the CBCT is very useful for this purpose. If it is not possible to determine this trajectory through radiological evaluation, we will have to probe the foramen with a periodontal probe to assess the extension and direction of the anterior loop. We will translate this extension and direction to the external wall of the bone to determine the position and angulation of the posterior implant. As a rule, it is necessary to ward off 2–3 mm from the mental foramen or the anterior loop of the alveolar canal for safety.

In the upper jaw, the position of the posterior implants is determined by the anterior wall of the maxillary sinus. Again, panoramic x-ray or panoramic view of CBCT is useful to determine it. In cases of doubt, it is necessary to create a little lateral window to the maxillary sinus and with a periodontal probe sound the anterior sinus wall and translate the measures to the external side of the bone. In this way it is possible to determine the limit of the posterior implant.

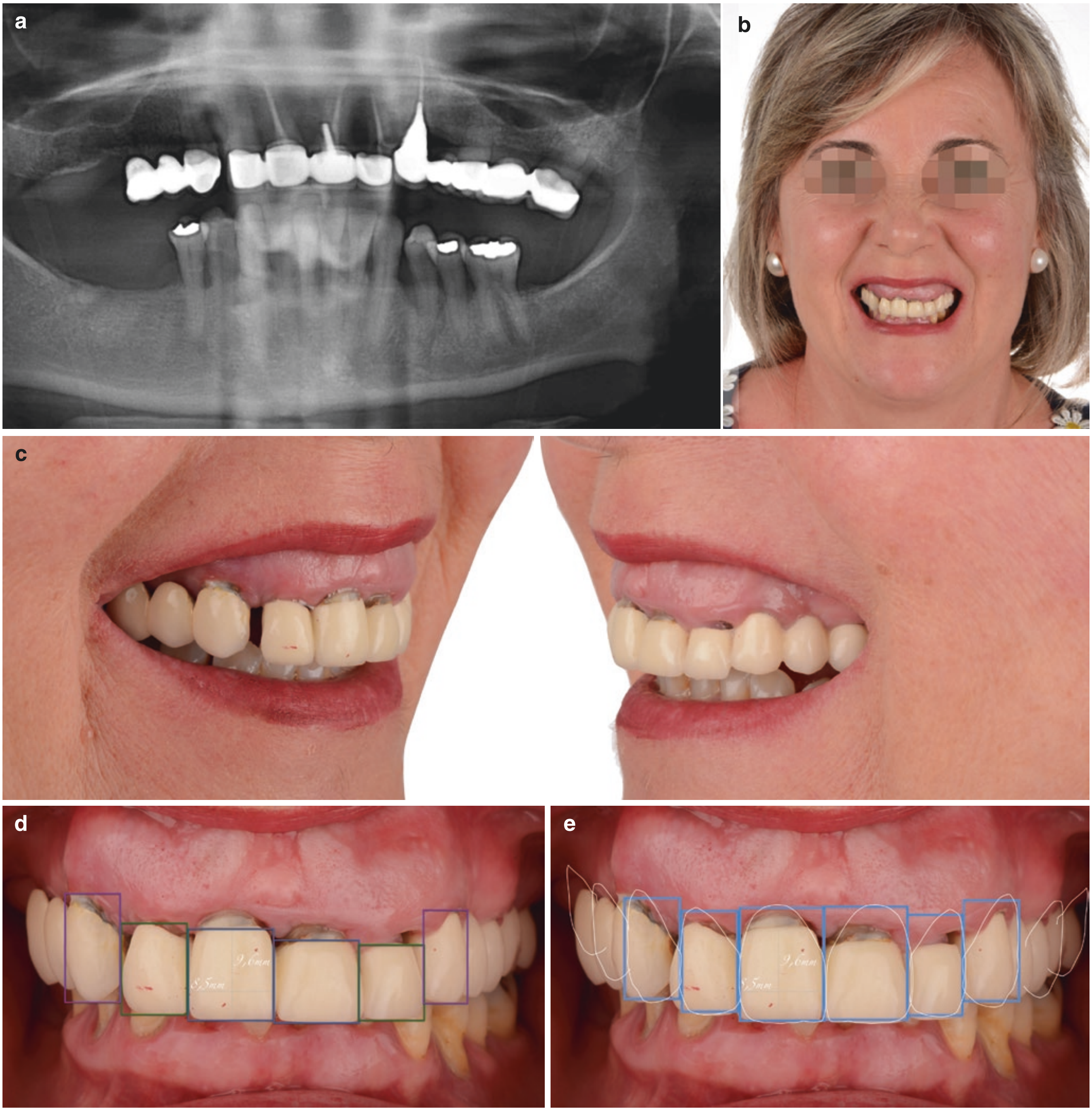

Fig. 7 (**a**) Initial panoramic x-ray of the patient showing multiple restorative procedures, the presence of broken teeth and periodontal disease. (**b**) Extraoral view of the patient. Gummy smile. The patient demands an improvement of her dental esthetics. (**c**) Gummy smile of the patient, right and left views. These cases are very demanding for the surgeon because it is mandatory to hide the transition line above the lip line. (**d**) Incorrect proportions of the anterior teeth. (**e**) Digital smile design to valorate the correct proportion and disposition of the future anterior teeth

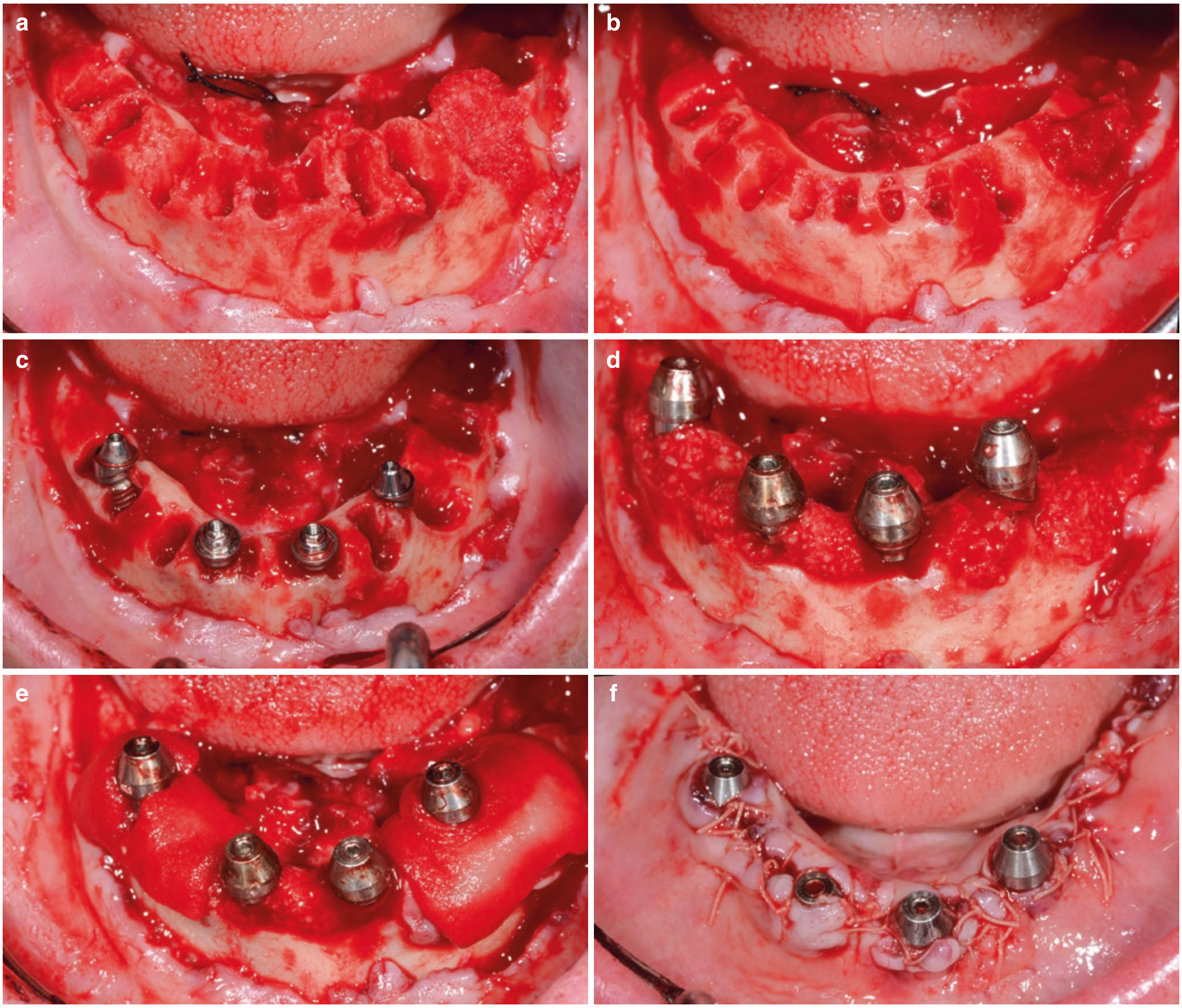

Fig. 8 Surgery of the mandible. (**a**) Full-thickness flap elevated after teeth extractions. (**b**) Regularization of the alveolar crest to create a flat surface. (**c**) Four implants placed with the prosthetic abutments. Two axial anterior implants and two tilted posterior implants (Intraoss®, Implantes Odontológicos, São Paulo, Brasil). (**d**) Autogenous bone graft placed to cover peri-implant defects and filling of the post-extraction sockets. (**e**) Collagen membranes were adapted around the implants to cover the bone graft. (**f**) Suturing of the flaps

Bone Remodeling

After locating the posterior limits, the next step is to regularize the bone ridge to create a flat surface to position the implants. In post-extraction cases, careful debridement should be done to remove all granulation tissue. Bone remodeling can be done with manual instruments (as Gubia or bone scrapers), burs mounted in a handpiece, or with a piezosurgery device. The objective in the mandible is to obtain a 5 or 6 mm flat bone platform. When we have a narrow or knife-edge ridge, lowering the alveolar process will allow a greater buccolingual surface, eliminating the need of bone augmentation procedures and allowing the fabrication of a cleansable prosthesis.

In the maxilla when possible, we will do the same, and remodel the bone to obtain a wide flat platform before drilling the implant osteotomies. However, it is not necessary to obtain such a bone width because there is the possibility of inserting the implants in a palatal position.

In the maxilla, however, it is of capital interest for the final esthetic results of the rehabilitation to hide the transition line of the prosthesis with the lip. For this reason in the preoperative assessment of maxillary cases, we must determine if the patient shows the alveolar process when smiling.

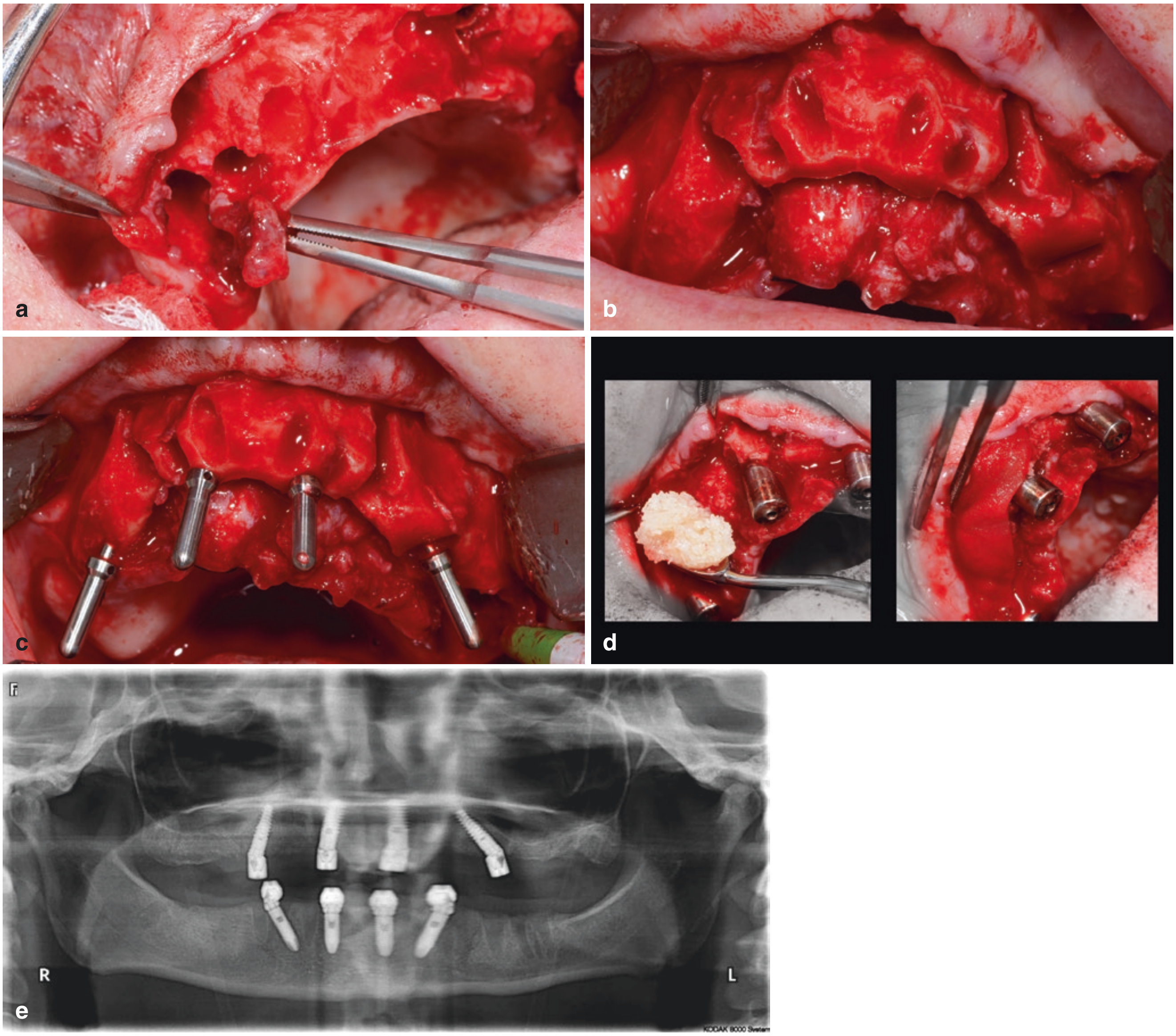

Fig. 9 Surgery of the upper maxilla. (**a**) After teeth extractions and full-thickness flap elevation, all granulation tissue was removed. (**b**) Regularization of the alveolar crest. (**c**) Direction pins used during implant bed preparation. See the angulation of the most posterior. For all the implants, a palatal approach was followed to maintain a thick cortical buccal bone around the implants (Intraoss®, Implantes Odontológicos, São Paulo, Brasil). (**d**) Bone substitute used to cover the peri-implant dehiscence and covered by a collagen membrane. (**e**) Post-surgery panoramic x-ray showing four implants placed both in the maxilla and mandible

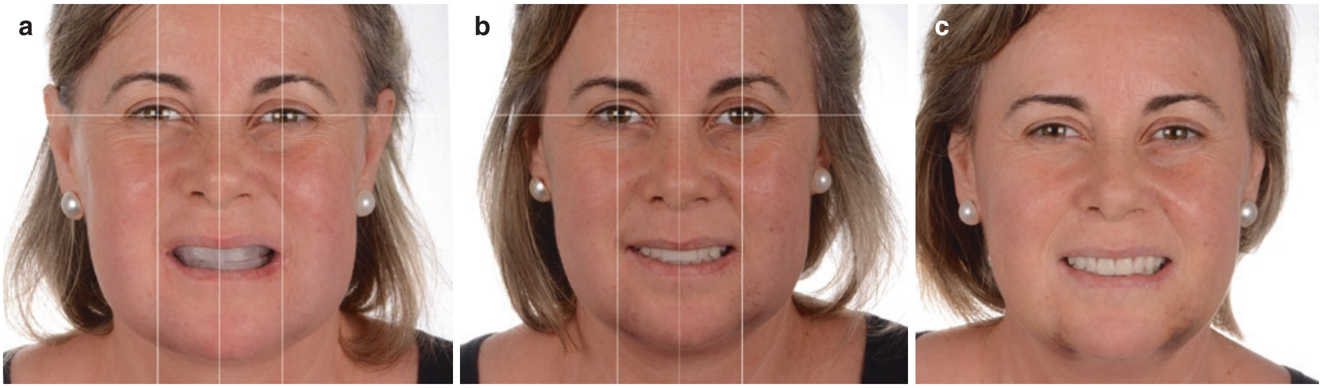

Fig. 10 Immediate loading prosthetic procedure. (**a**) Wax bite to valorate vertical dimension of occlusion (VDO), smile line, and teeth position. (**b**) Teeth trial to valorate the occlusion and esthetics. (**c**) Extraoral view of the temporary prosthetic rehabilitation 24 h after the surgery

In these cases, we will measure how much alveolar process the patient shows. The final bone reduction will consider the amount of alveolar process shown by patient and 5 mm extra to ensure a final esthetic result.

Implant Placement

The next step will be to prepare the implant osteotomies and insert the fixtures. It is recommendable to start with the posterior ones. The literature supports the use of regular diameter implants—minimum width of 3.5–4 mm and 10 mm in length—to provide enough mechanical strength, prevent fractures of the components and achieve primary implant stability that allows immediate loading. A minimum insertion torque of 35–40 Nw is recommended. Depending on the quality of the bone, the underpreparation of implant bed, bicortical anchorage, the use of bone expanders, absence of tapping, or more aggressive implant designs can be advisable.

The tilting of the posterior implants will be between 30° and 45° mesio-distally, with the objective of increasing the arch length and reducing the distal cantilever. Depending on the anatomy of the patient (mental foramina and maxillary sinuses), distal implants emerge in the first or second premolar or first molar position. In cases with a wide pneumatization of the maxillary sinus that provoques an emergence of the posterior implant at the cuspid level, a change in the treatment plan is necessary, and a zygomatic implant is required to allow enough arch length.

The anterior implants are placed parallel to each other at the level of the lateral incisors both in the maxilla and mandible. In the mandible the implants must follow the ridge angulation. This sometimes entails the use of angulated abutments because the implants have a backward angulation. In the maxilla if there is not enough bone width, a palatal position is recommended.

Once implants are installed, if primary stability is sufficient, angulated abutments (30° or 17°; depending on the final implant angulation) are connected to the posterior implants, and standard straight abutments were connected to the anterior ones, screwed with the torque recommended by the manufacturer. After this, flaps are sutured.

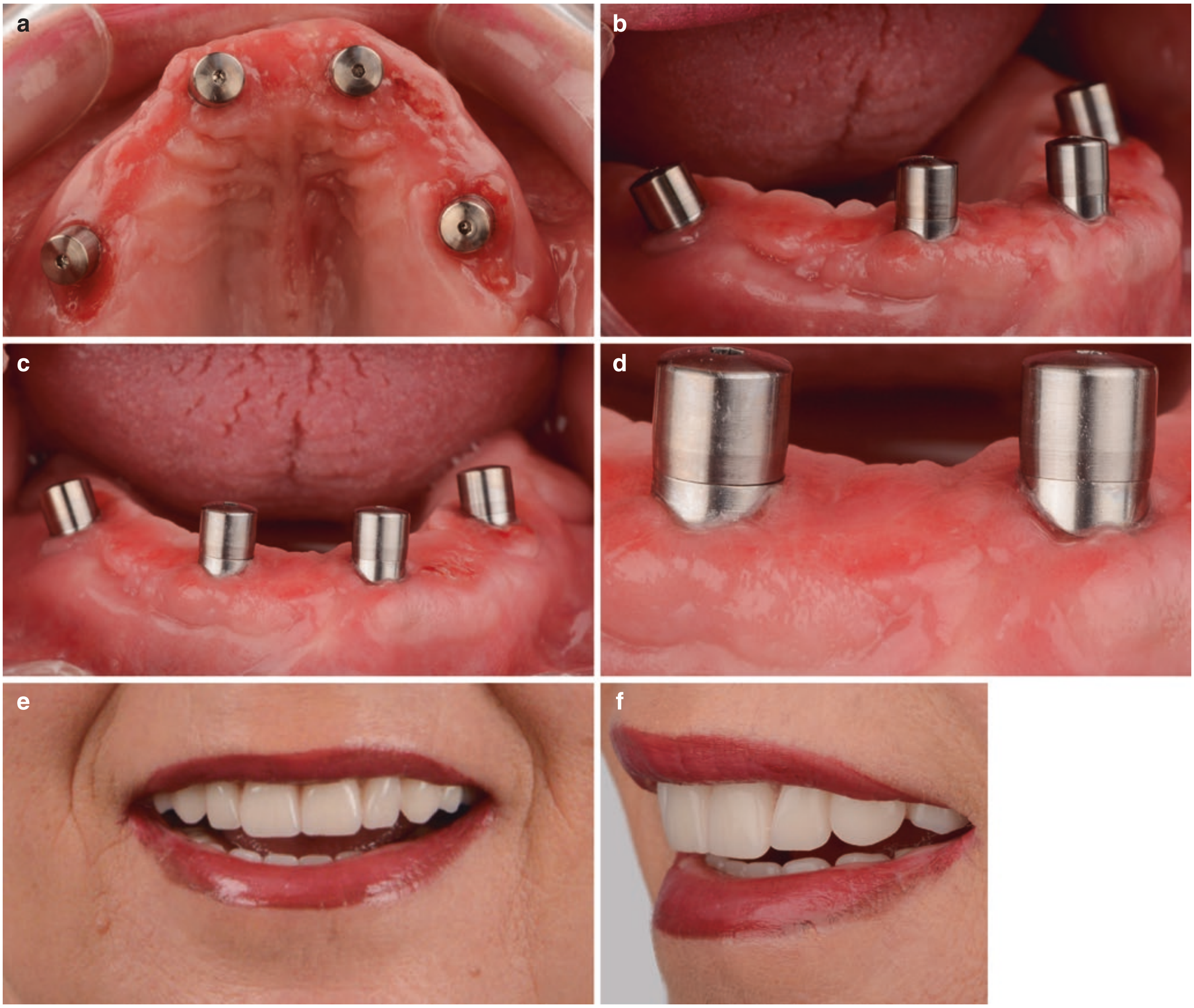

Fig. 11 (**a**) Occlusal aspect of the peri-implant mucosa at 4 months, in the moment of the final impressions. (**b**) Lateral and (**c**) frontal view of the lower peri-implant mucosa at 4 months. (**d**) Detail of the peri-implant mucosa of the axial implants. (**e**) Frontal and (**f**) lateral view of the definitive restoration

Fig. 12 (**a**) Extraoral view of the patient. The patient presents a decrease in the VDO. (**b**) Intraoral frontal view of the patient showing multiple teeth lost, gingival inflammation, and bone atrophy. (**c**) Occlusal view of the upper maxilla. (**d**) Occlusal view of the mandible. (**e**) Initial panoramic x-ray showing severe periodontal disease and peri-implantitis. (**f**) Coronal view of the CBCT of the patient showing insufficient bone height in the posterior areas both in the maxilla and mandible. (**g**) Axial view of the CBCT of the upper maxilla showing a big bone defect in the premaxilla associated with a periapical lesion in the maxillary central incisor. (**h**) An all-on-four was the proposed treatment plan for the upper maxilla and (**i**) the mandible

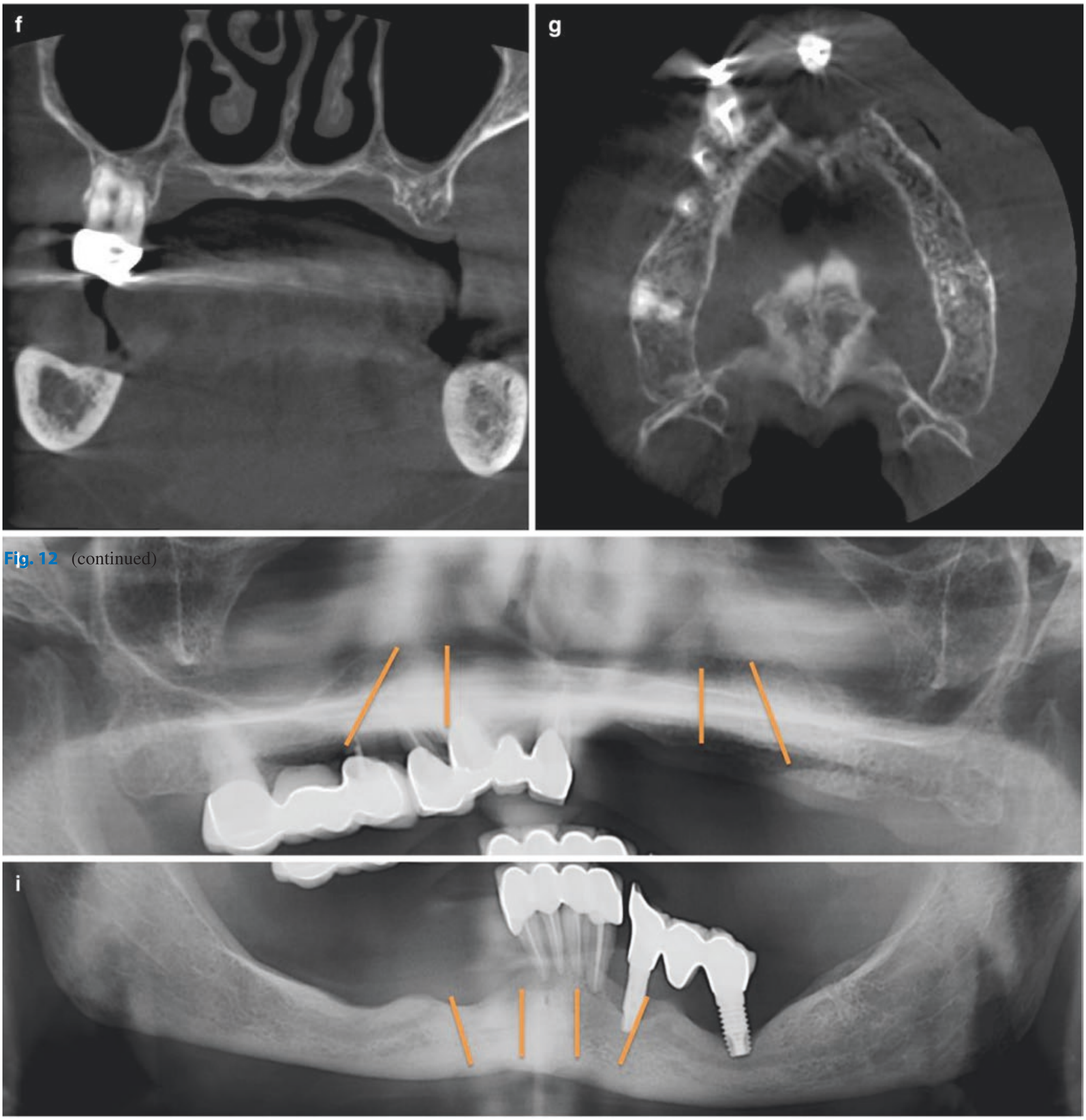

Fig. 12 (continued)

Prosthetic Procedure

Once the flaps are sutured, there are several alternatives to obtain an immediate loading fixed prosthesis. These alternatives are better explained in chapter "Immediate Loading with Fixed Full-Arch Prosthesis in the Edentulous Patient: Treatment Protocol."

A first alternative is to use a laboratory-based or indirect technique, in which implant positions and inter-arch registration are performed and sent to the laboratory. The dental technician will fabricate in 1–2 days the provisional full-arch acrylic restoration without cantilever extensions. Healing abutments are placed until provisional restoration is delivered.

A second alternative is to use a chairside or direct technique, which consists in adapting a complete denture of the patient. Temporary titanium abutments are placed, and holes are made in the complete denture through which the abutments emerge. Care is taken in positioning accurately the denture in the mouth after cutting the temporary abutments to the correct height. After this, the abutments are fixed to the denture with acrylic resin. After

Fig. 13 Surgery of the mandible. (**a**) Initial situation after teeth and implant extraction. (**b**) After a flap was raised and an ostectomy was realized to flatten the alveolar crest, four implants were placed (TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**c**) Prosthetic abutments were placed to correct discrepancies in angulation between implants. (**d**) An autogenous bone graft was used to cover peri-implant defect dehiscences. (**e**) A-PRF membranes were used to cover the grafts (A-PRF™, Process for PRF, Nice, France). (**f**) Flap suture

hardening of the resin, the provisional restoration is unscrewed, polished, and adapted—the distal extensions eliminated as well as the buccal extension of the prosthesis and the palate.

When using either technique, a flat or convex base of the prosthesis is recommended to allow hygiene procedures.

In both cases a passive fit of the prosthesis is mandatory, and a panoramic x-ray is recommended to assess the adjustment. Occlusal contacts are checked, and a centric relation occlusion is provided with well-distributed contacts. The screws are tightened at approximately 15 Ncm or according to the manufacturer's recommendation.

Postoperative Care

The patient receives postoperative instructions and pharmacologic therapy that consist in antibiotic therapy (amoxicillin 500 mg, one capsule every 8 h for 7 days/or clindamycin

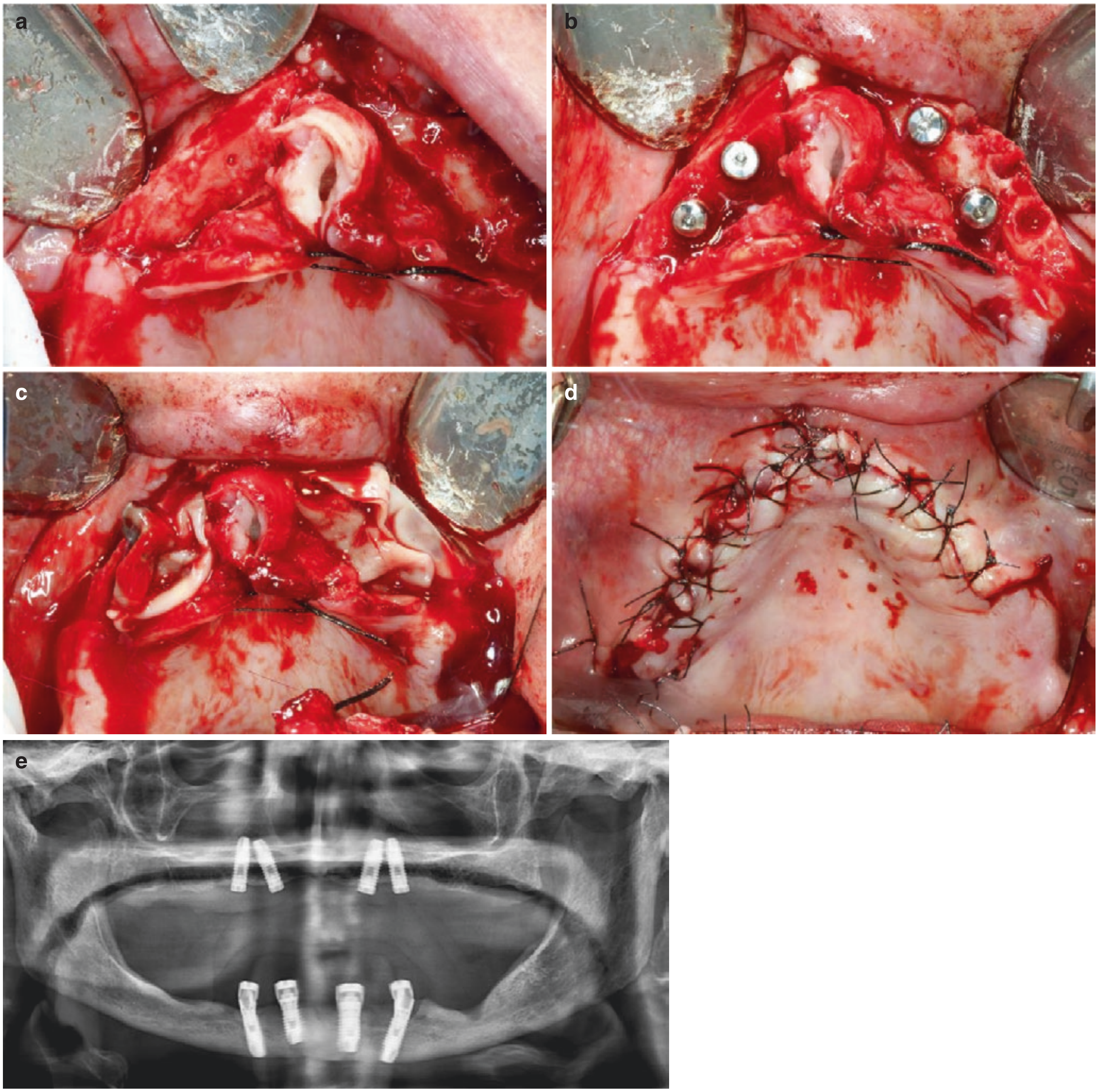

Fig. 14 Surgery of the maxilla. (**a**) A big bone defect was found in the premaxilla after flap elevation. (**b**) Four implants were placed palatally avoiding the bone defect and maintaining a thick buccal bone (TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**c**) An autogenous bone graft covered with A-PRF membranes was used to fill bone defects around implants (A-PRF™, Process for PRF, Nice, France). (**d**) Caused by a low implant primary stability, it was decided to let the implants heal submerged with a delayed loading. (**e**) Final panoramic x-ray after surgery

300 mg in cases of allergy), anti-inflammatory medication (ibuprofen 600 mg, one capsule every 8 h for 3 days), and 0.2% chlorhexidine mouthwash rinses (two to three times/day). One week after the intervention, the sutures are removed and oral hygiene instructions explained to the patient. This must involve the use of interdental brushes, irrigator, and any device that can help the patient clean the area underneath the prosthesis. During the 2–3 months of the osseointegration period, the patient must follow a soft diet.

After a period of 3–6 months, the procedures to fabricate the definitive prosthetic rehabilitation can start.

Fig. 15 (**a**) After surgery the position of the healing caps was registered in the temporary prosthesis of the patient using an impression material. (**b**) After this, the prosthesis was perforated with a bur in the position of the implants, and the fitted was checked. (**c**) A rubber dam was positioned around the temporary abutments. The temporary prosthesis was fixed to the temporary abutments using pink self-curing resin. (**d** and **e**) All empty gaps around temporary abutments were filled with the resin and polished. It is extremely important to obtain a flat or concave base of the prosthesis to improve the oral hygiene of the patient and avoid food retention. (**f**) Extraoral aspect of the patient 1 week after surgery. (**f** and **g**) Intraoral aspect of soft tissues 1 week after surgery in the moment of suture removal

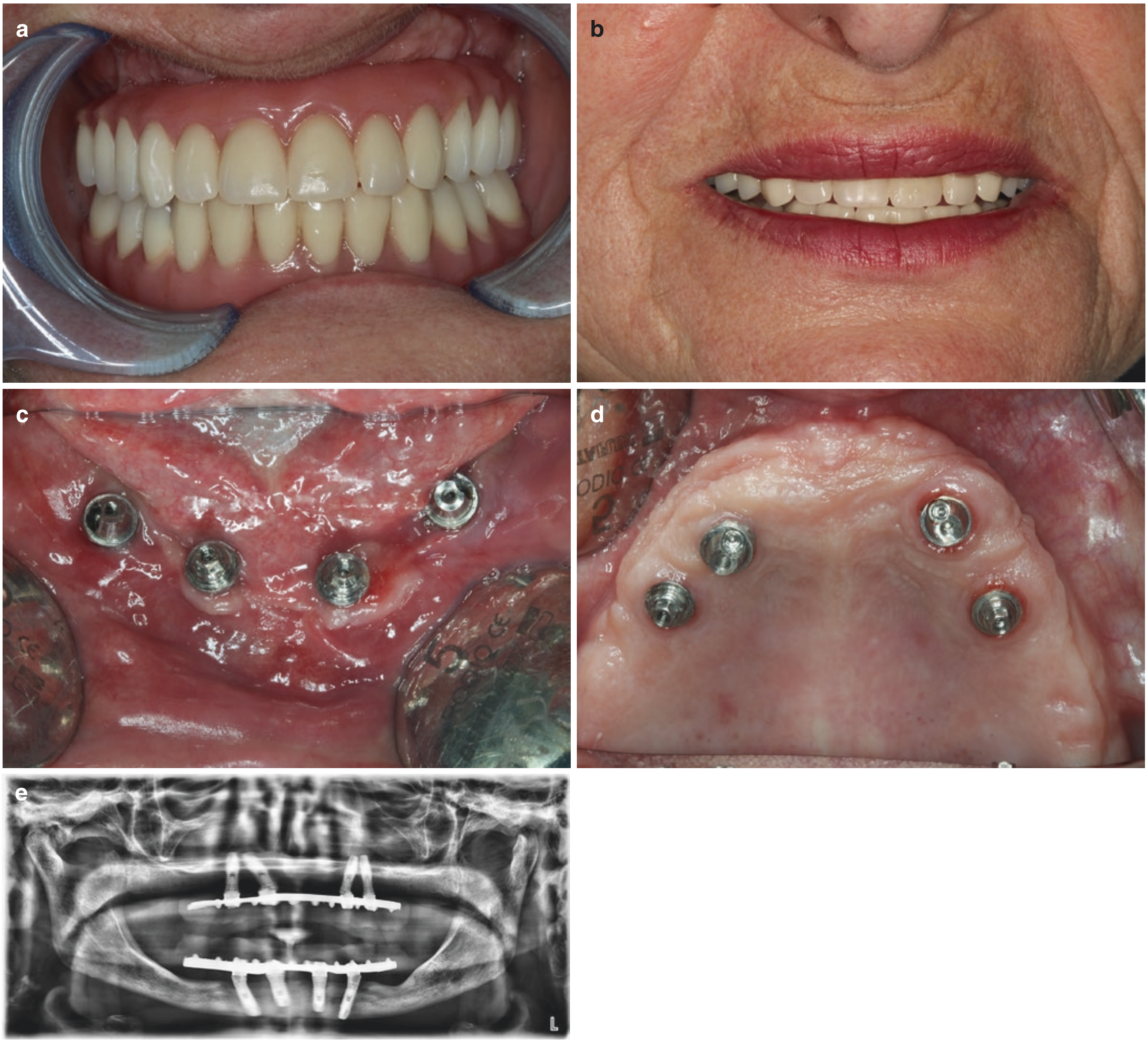

Fig. 16 (**a**) Intraoral and (**b**) extraoral view of the definitive restorations at 4 months. (**c**) Occlusal aspect of the peri-implant mucosa in the mandible and (**d**) in the maxilla at 4 months. (**e**) Panoramic x-ray with the definitive prosthesis at 4 months

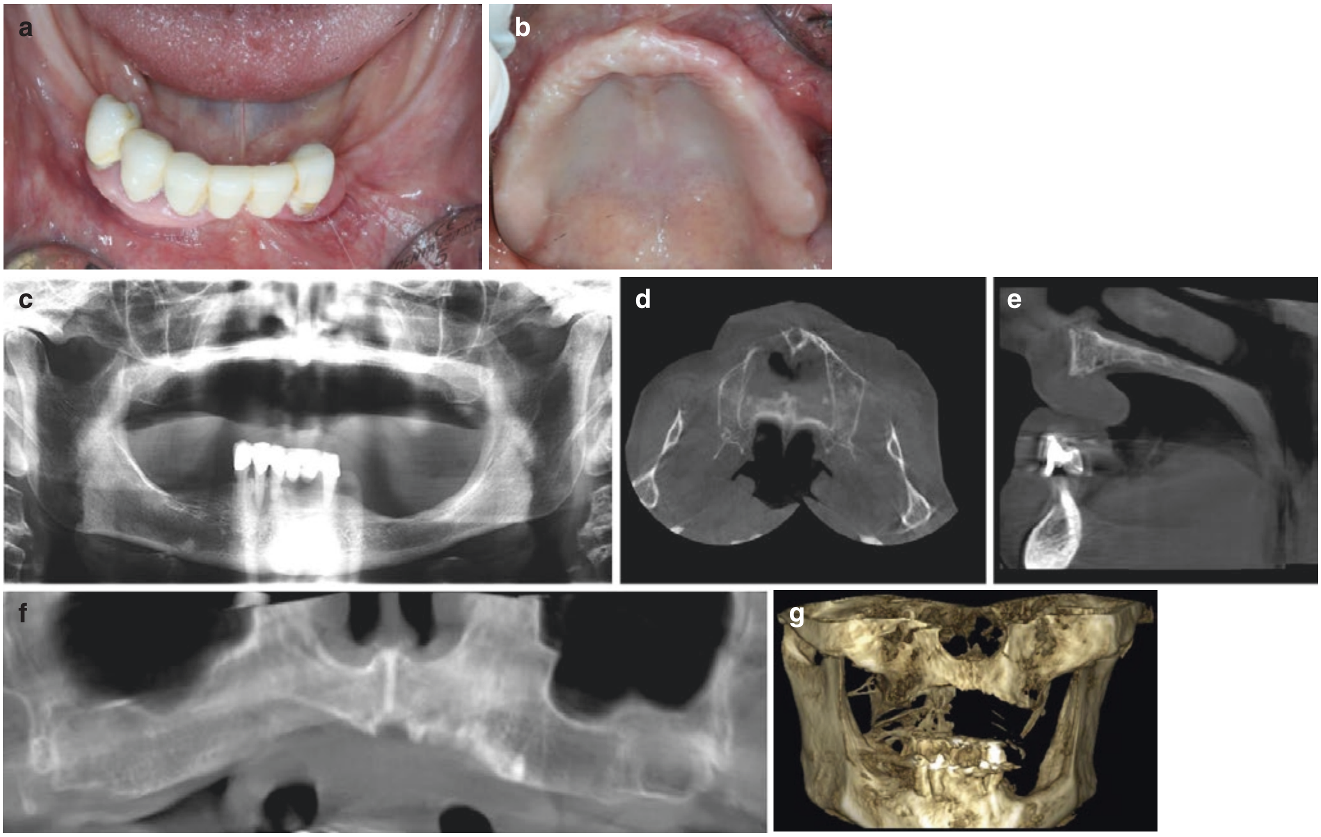

Fig. 17 (**a**) Initial intraoral situation of the patient; mandible and (**b**) maxilla. (**c**) Initial panoramic x-ray showing periodontal disease of the lower teeth associated with periapical lesions. (**d**–**f**) Axial, sagittal, and frontal view of the CBCT of the patient. The patient present a class V atrophy of Cawood and Howell. (**g**) 3D reconstruction of the CBCT. See the narrow superior alveolar crest

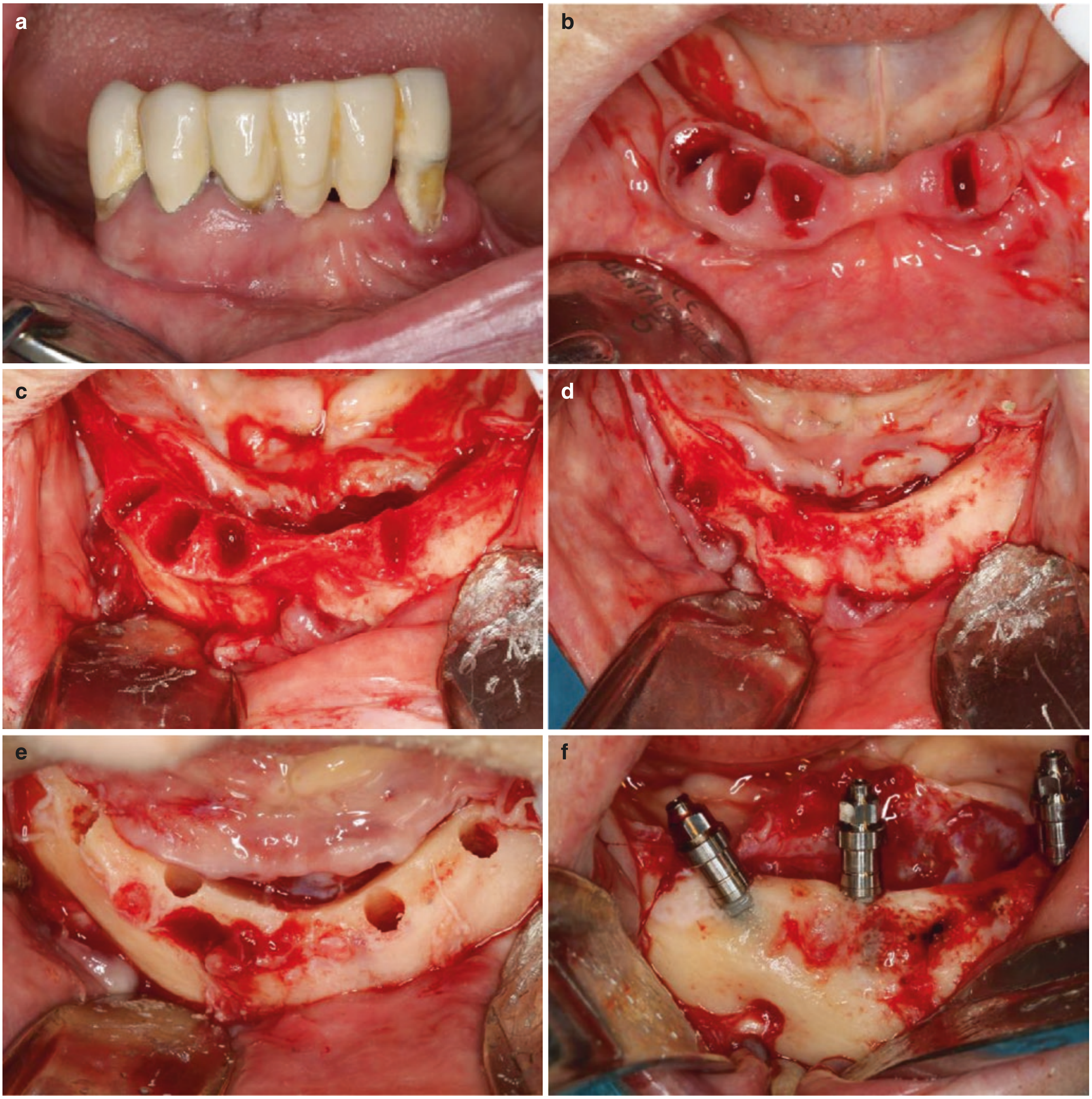

Fig. 18 Surgery of the mandible. (**a**) Preoperative situation. (**b**) Teeth extractions. (**c**) Flap elevation and localization of mental foramen. (**d**) Aspect of the alveolar crest after ostectomy. (**e**) Implant bed preparation. (**f**) Implant position (TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). By tilting the posterior implants, it is possible to obtain a more distal emergence compared with axial implant position, saving the mental foramen and the anterior nerve loop, obtaining a better A-P spread of the implants, and reducing prosthetic cantilever. (**g**) Prosthetic abutments in place. (**h**) Flap suture. (**i** and **j**) Splint of the impression abutments. (**k**) Temporary prosthesis. Detail of the flat base. (**l**) Intraoral view of the temporary prosthesis

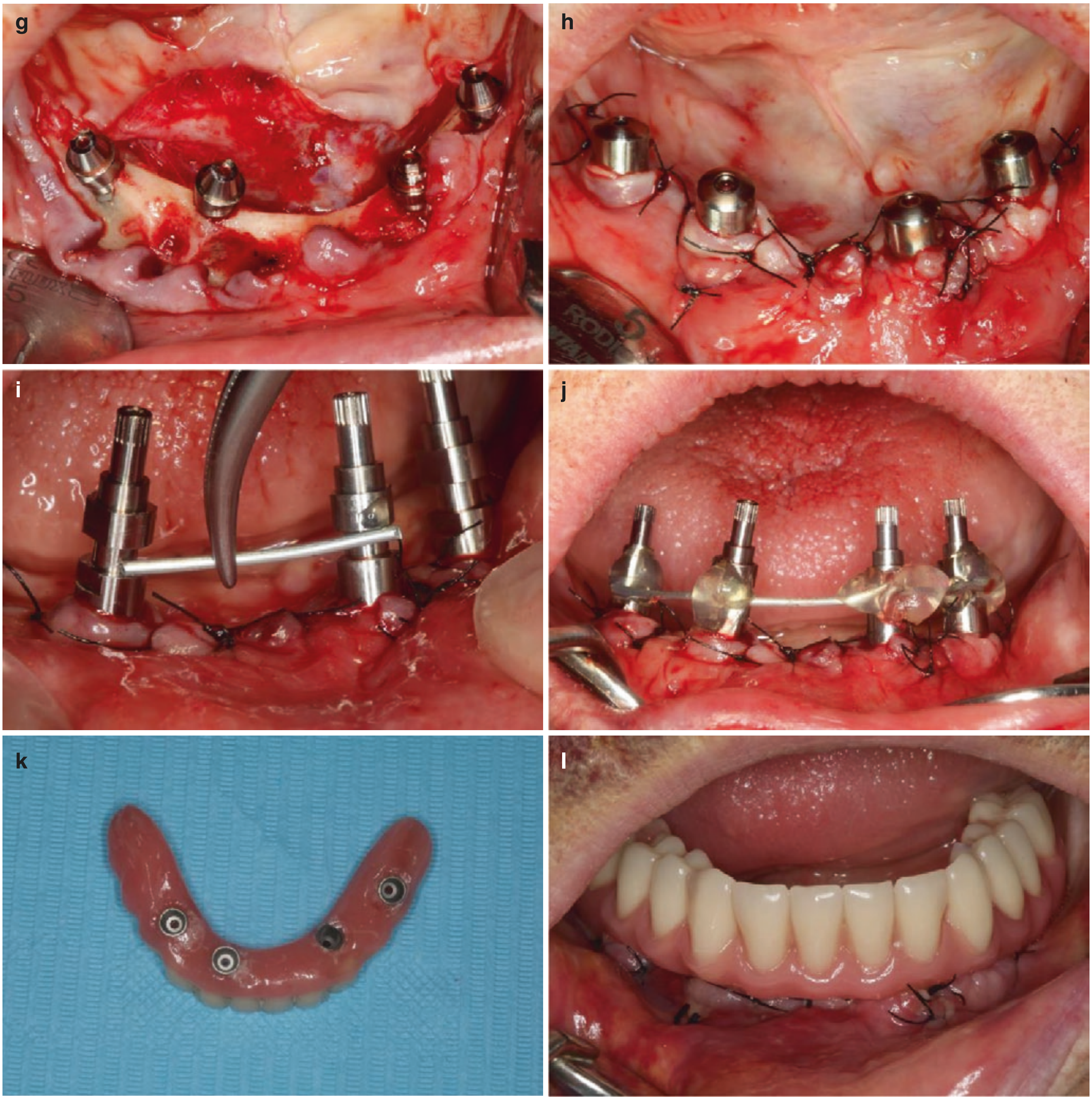

Fig. 18 (continued)

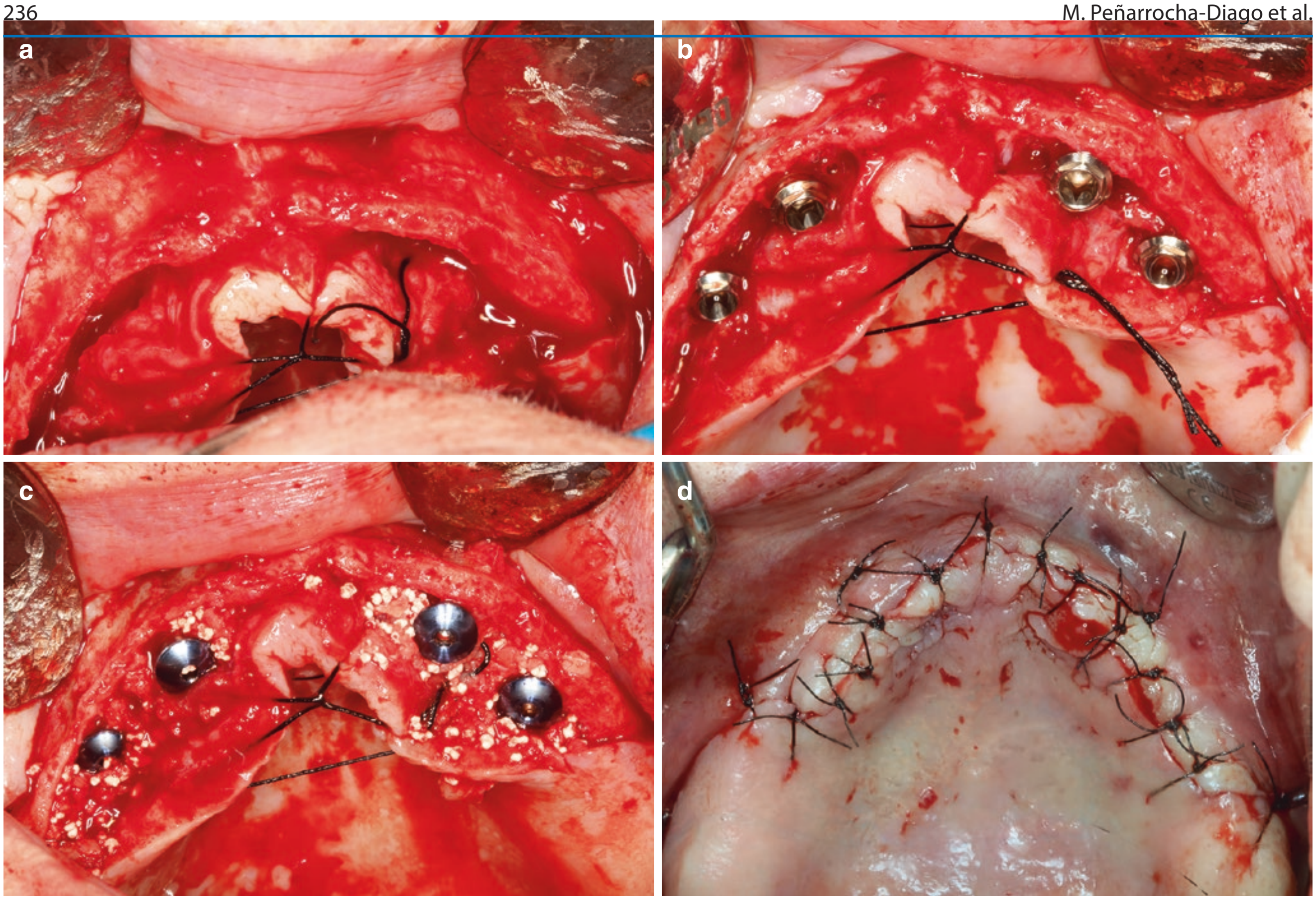

Fig. 19 Surgery of the upper maxilla. (**a**) Narrow alveolar crest. (**b**) Four palatal implants were placed (TSH®, Phibo Dental Solutions, Sentmenat, Barcelona, Spain). (**c**) Bone regeneration of the palatal exposed threads (KeraOs®, Keramat, Ames, A Coruña, Spain). (**d**) Flap suture. (**e**) Postoperative panoramic X-ray. (**f** and **g**) Aspect of the soft tissues after 1 week in the moment of suture removal at both lower and upper maxilla

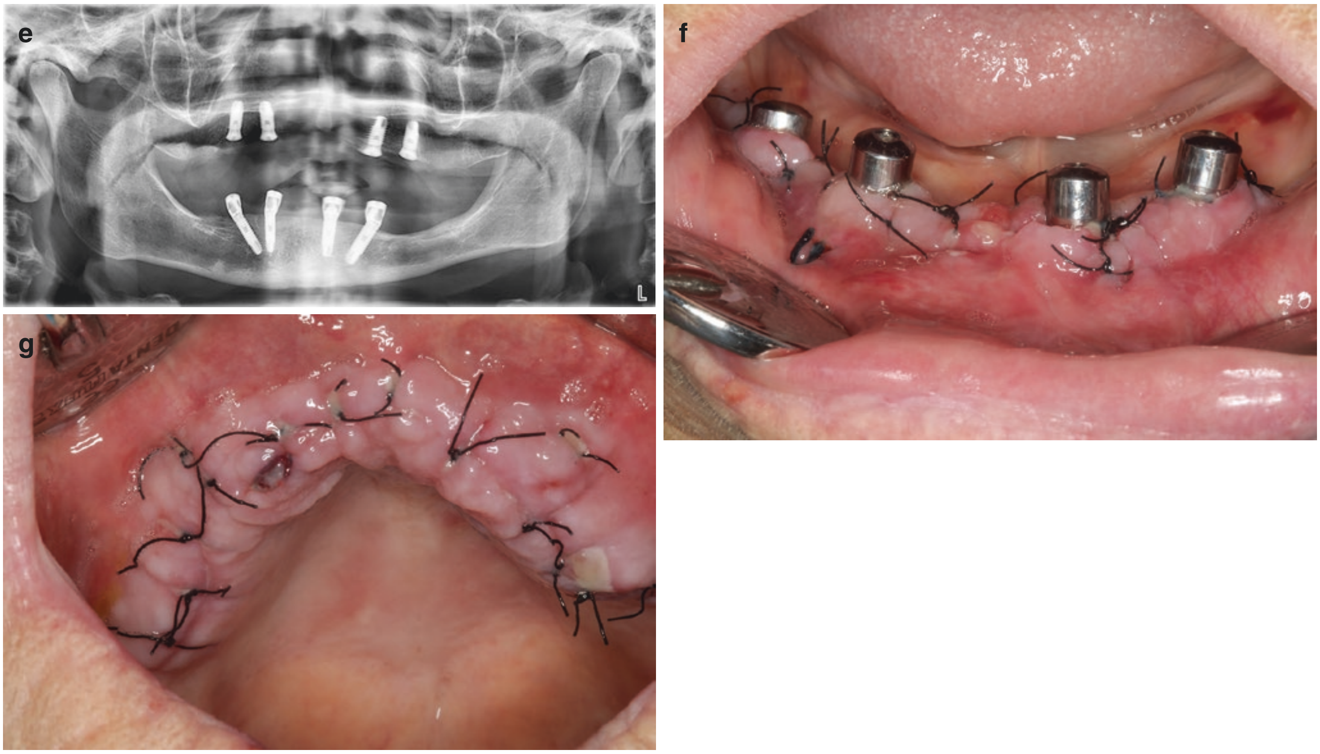

Fig. 19 (continued)

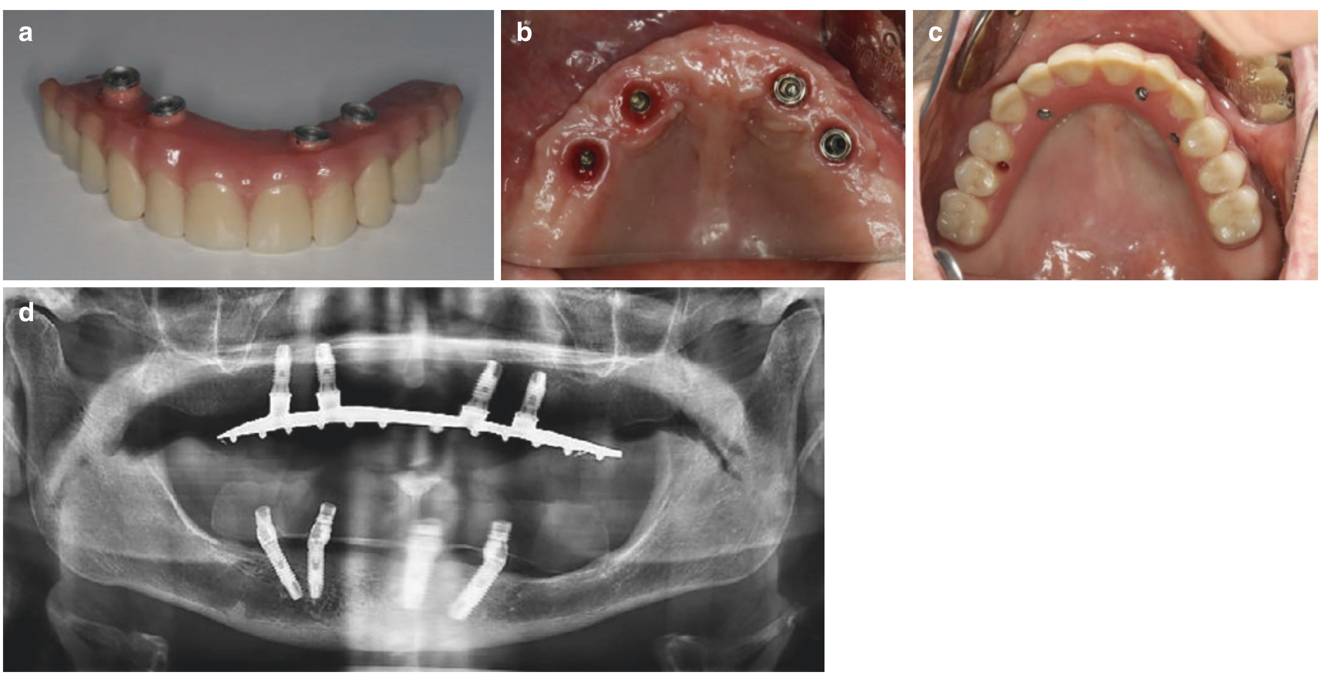

Fig. 20 Definitive prosthesis of the upper maxilla. (**a**) Detail of the prosthesis. (**b**) Peri-implant soft tissue aspect at 4 months. (**c**) Occlusal view of the definitive prosthesis. (**d**) Panoramic x-ray at 4 months. The patient still continues with the temporary prosthesis of the lower jaw

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Immediate Loading of Mandibular Overdentures

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Take-Home Message

Immediate loading of mandibular overdentures is indicated for patients with a physical or psychological intolerance of conventional removable prostheses (dentures); this type of treatment also overcomes the problem of the edentulous period following implant placement.

Correct patient selection and treatment planning are essential to ensure treatment success, as well as close collaboration between dentist and prosthetics laboratory, as the procedure requires exact timing.

The ideal treatment protocol involves four intermentonian implants (as the intermentonian area offers excellent bone quality, facilitating primary stability), splinted by a retention bar to eliminate micromovement.

The implants must be at least 10 mm long with a surface treatment that will maximize primary stability and reduce the time required for osseointegration.

The recommended follow-up period is 24 months after implant placement and should consist of clinical and radiological check-ups of the implants, retention bar, and overdenture.

Treatment outcomes are comparable to conventional loading protocols and enjoy success rates close to 100% over a 5-year follow-up.

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Introduction

Immediate loading in the mandible is one of the most usual restoration procedures in implant dentistry. In patients who have worn mucosa-supported complete prostheses for a long time, occlusal force decreases dramatically from 1.378 to 0.038 Mpa after 15 years wearing a denture; this reduction in force is accompanied by improved masticatory efficiency (Carr and Laney 1987; Rissin et al. 1978) and a higher level of patient satisfaction. For this reason, the introduction of implant-supported complete mandibular overdentures can be considered an important advance in the field of dentistry (Friberg et al. 1991).

The first published investigations of this treatment involved mandibular subperiosteal implants or root-shaped implants, immediately stabilized and loaded, in the anterior region of the mandible (Babbush et al. 1986). Since these early initiatives, numerous patients have benefited from the increased retention and additional support provided by implant-based restorations in general and implant-supported overdentures in particular. Rehabilitative treatment with overdentures has become an alternative to mucous-supported complete prostheses (conventional dentures), which patients regard as an uncomfortable and inconvenient form of rehabilitation. In most cases, dentures are now regarded as a provisional, temporary, aesthetic, and functional measure during implant-based treatments. Moreover, it should be noted that the bone loss produced during the first year after losing teeth is ten times that of the following years. When multiple extractions are performed, this usually involves a bone loss of 4 mm during the first 6 months. As the bone ridge resorbs, muscle attachments reach the level of the edentulous ridge (Tallgren 1966).

In the early years of implant dentistry, implants remained unloaded for a minimum of 3 months in the mandible and 6 months in the upper maxillary in order to facilitate and protect implant osseointegration (De Smet et al. 2007; Stephan et al. 2007). Patients were obliged to remain in an

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edentulous state throughout this osseointegration period or to wear a removable dento-/mucous-supported denture. This loading protocol continued for over a decade until in 1979 Ledermann published a study of 138 patients who received 476 mandibular implants. These were loaded immediately, splinting with a bar supporting an overdenture. After a 6-year follow-up, this protocol obtained a success rate of 91.2%.

This type of treatment is especially recommended for those patients who present a physical or psychological intolerance of dentures, as immediate loading avoids the need for removable prostheses during osseointegration. In fact, the Mcgill consensus statement on overdentures (Montreal, 2002) established a series of criteria for different therapeutic alternatives for the edentulous mandible, whereby rehabilitation by means of an implant-supported overdenture is now considered a standard treatment, the first choice for patients already wearing dentures and complaining of reduced quality of life (Feine et al. 2002).

In this way, immediate loading of implants placed in the edentulous mandible is not a recent concept (Ledermann 1979; Schnitman et al. 1990). But the development of new implant surfaces that improve primary stability (Cannizzaro and Leone 2003) and promote osteoinduction have shortened the osseointegration period (Buser et al. 2004), and it is for this reason that early loading protocols have gained popularity. Research has reported high success rates for immediately loaded implants, whether splinted or not (Maniatopoulos et al. 1986). Immediately loaded implants are splinted to avoid micromovement affecting the bone-to-implant interface (Romeo et al. 2002). However, the literature does not provide conclusive evidence to support the idea that survival rates depend on the loading protocol alone; success is also dependent on the type of implant used, the number of implants, the retention system, and so on (Stephan et al. 2007; Liddelow and Henry 2010; Marzola et al. 2007).

To carry out this type of treatment, it is necessary to select patients suited to bilateral anchorage, using a minimum of four intermentonian, textured surface implants with a minimum length of 10 mm and minimum insertion torque of 40 N/cm. The sites for implant placement are determined by the specific characteristics of the mandibular bone, with a thick cortex and dense cancellous bone, which allow a high percentage of bone-to-implant contact (Enríquez-Sacristán et al. 2011).

Although the literature describes cases of rehabilitations supported by two mandibular intermentonian implants with immediate loading, and even one symphyseal implant, we believe that treatment outcomes and prognosis will be improved by following the protocol described below.

Planning

Anamnesis

The first contact with the patient is of great importance in implant-based treatment, especially in cases in which immediate loading may be an option. It is essential to provide the patient with a clear and simple explanation of the procedure and alternative options, as well as the possible outcomes, complications, and economic cost. During the meeting, it is advisable to adopt a cautious attitude with respect to the outcome and to avoid overpersuasion of patients who express uncertainty, unless it has been determined beyond doubt that immediate loading will be an appropriate option for the particular clinical case.

If the patient presents some general medical condition, his/her doctor should be consulted to avoid any interference in the patient's general healthcare. Likewise, if any psychological disorders are detected, these should be carefully assessed and heeded with caution.

Clinical Exploration

Extraoral (facial and muscular biotype, smile line, and maxillomandibular relation) and intraoral examination (mouth opening, oral hygiene, amount of gum insertion, or the presence of hyperplasias, tumors, etc.) provides a clearer view of whether or not immediate loading is the right treatment for the individual. Study models will make it possible to assess the characteristics that will determine the design of the future prosthesis and to check the details of the prosthesis before placing implants.

Information obtained by means of a questionnaire filled out by the patient, together with clinical exploration, will provide all the data necessary for indicating or contraindicating an implant-supported overdenture as the treatment of choice. Contraindications for this treatment include parafunctional habits, patients with high muscle strength, and unfavorable intermaxillary relationships (severe Class II or III).

Photographic Study

Although it is not absolutely necessary, it advisable to obtain a photographic register before treatment, which will allow us to see the results of treatment and may be useful in case of any lawsuit.

Radiological Study

When clinical exploration has been completed, providing no contraindications have been identified, the quality and quantity of bone at the implant sites must be analyzed, as bone density is the fundamental parameter governing primary stability, implant rigidity, and immobility. To do this (as with cases involving conventional loading protocols), a radiological study based on panoramic radiographs and tomography must be performed before proceeding to implant insertion.

Panoramic radiographs will reveal any bone pathology that could contraindicate implant surgery, but the two-dimensional image does not show the thickness of the alveolar ridge. To visualize this dimension, a computerized tomography (CT) must be used to assess bone quality, and especially quantity. In recent years, cone beam computerized tomography (CBCT) has replaced CT due to its lower doses of radiation and the high quality of the images produced.

Prosthetic Phase

When radiological study has confirmed the presence of sufficient bone quality and quantity, the pre-surgical prosthetic phase begins. This proceeds in the same way as a conventional complete denture. Impressions are taken with alginate using a standard tray from which study models are fabricated. A rolled wax baseplate is made to register intraoral relationships and to mount the models in a semi-adjustable articulator. While mounting models in an articulator is always advisable, in the case of implant-supported overdentures, it is absolutely essential because:

1. It provides information about the occlusal plane and the available prosthetic space, making it possible to order the system's attachments in advance, so that the laboratory will be able to supply the elements on time.
2. It will make it possible to choose the type of retention, in this case bars, as well as their height and extension.
3. It will be possible to perform an accurate setup of the artificial teeth and obtain an occlusal model necessary for fabricating any complete prosthesis, including implant-supported overdentures: bilateral balanced occlusion with the maximum amount of dental contact possible both in centric occlusion and in functional movement that aims to avoid displacement of the prosthesis and provide retention and stability.

Once the setup has been checked, it is sent to the laboratory together with the prosthesis prescription, requesting a dental wax-up with bilateral balanced occlusion for final checking.

When checking the wax-up, the two key points are the vertical dimension and the prosthesis' balance, as well as the usual tests relating to extension, retention, stability, and sealing. Registers of dental protrusion are taken and the patient's condylar inclinations are calculated, adjusting the articulator in accordance with these values and with the Bennett angle obtained by means of Hanau's formula.

With the articulator completely adjusted, it is returned to the laboratory, ordering an open surgical splint based on the wax-up and an individual perforated tray for the definitive impression taking.

With an immediate loading protocol, it is important to appreciate the key role played by the prosthetic laboratory. The working time is quite short, and so clear and timely communication with the laboratory staff will help to keep the treatment schedule on time.

As soon as the patient has been informed of the possible complications and risk of implant failure, and has given his/her consent to proceed, he/she is ready to undergo implant placement surgery.

Surgical Technique

For immediately loaded implants, the surgery technique is exactly the same as with conventionally loaded implants. After anesthetic infiltration into the lower alveolar, lingual, and mentonian nerves, a supracrestal incision is made in the inserted gum, raising a full-thickness mucoperiosteal flap to expose the entire alveolar crest in the surgical area; a midline releasing incision is made to assist visibility (Fig. 1). The

Fig. 1 Midline releasing incision (triangular incision) provides greater visibility of the surgical area

mentonian foramina must be located on both sides. This will avoid one of the most serious potential complications—lesioning of the mentonian nerve—which produces temporary or permanent paresthesia of the lip and chin, accompanied by severe discomfort.

The soft tissues must be treated atraumatically taking care to minimize inflammatory responses and patient discomfort when the prosthesis is fitted. The prefabricated surgical splint is then positioned, marking the sites where the implants are to be inserted.

Drilling is performed following the implant manufacturer's protocol. As soon as each implant is placed, primary stability must be checked for adequacy either by measuring insertion torque or performing resonance frequency analysis (RFA) (Fig. 2).

To obtain good primary stability, it is important to select the right implant design. The most commonly indicated implant has a self-tapping design with a pronounced thread that will help stabilize the implant at the moment of insertion. The recommended insertion torque should not be lower than 40 N/cm.

When the implants have been placed, the transporters are removed, and according to the system used, an open tray implant impression transfer can be placed (Figs. 3, 4, and 5), whose fit should be checked with radiographs. Alternatively (our preferred option, based on experience), closed tray transfers can be placed on dual-press abutments (Figs. 6, 7, and 8). Afterward the flap is sutured and impressions are taken with heavy, flowable silicone.

After impression taking, the transfers are unscrewed when the open tray technique is used or remain in place when the dual-press impression technique is used.

This phase ends with the placement of healing abutments. These should be high (5–7 mm) to avoid their being covered over as a result of inflammation (Fig. 9).

The usual postoperative measures are prescribed, as with any surgical intervention. In addition, antibiotics are administered for 7–10 days, anti-inflammatories for 2 or

Fig. 2 Drilled bone sites for implant placement

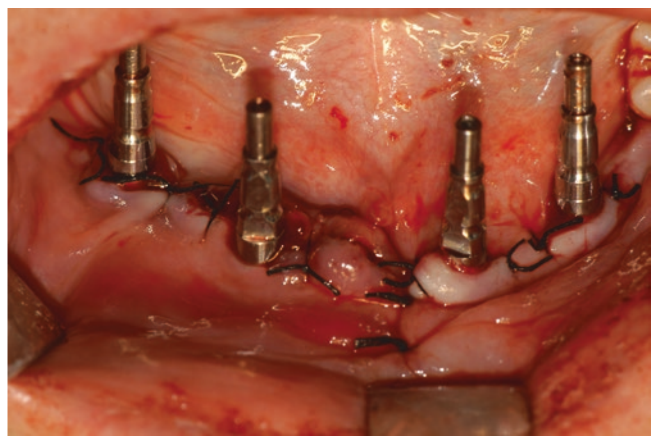

Fig. 4 Suture of the full-thickness flap with impression transfers in place

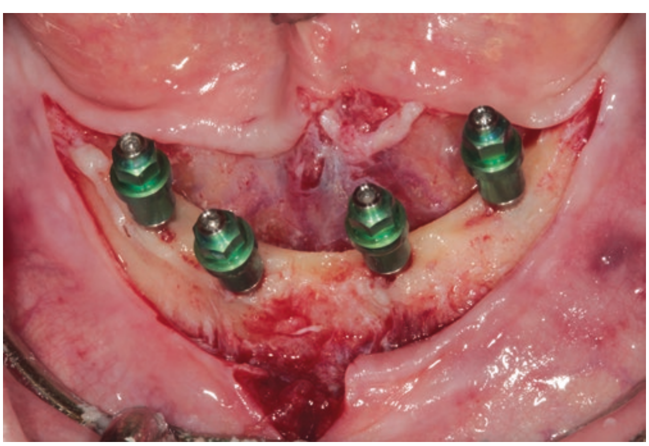

Fig. 3 Four intermentonian implants and transporters

Fig. 5 Transfers embedded in the impression material

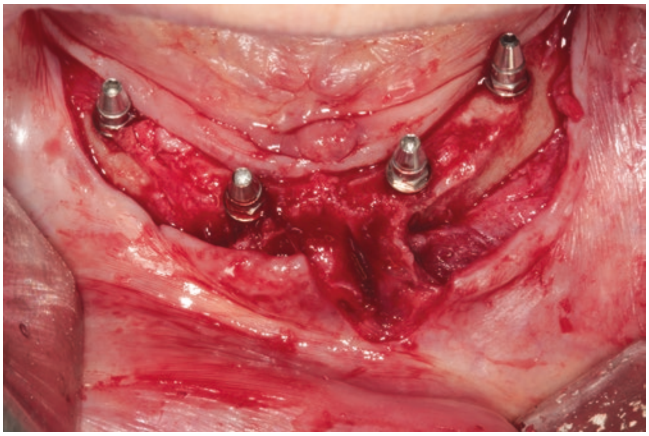

Fig. 6 Impression procedure with dual-press closed tray

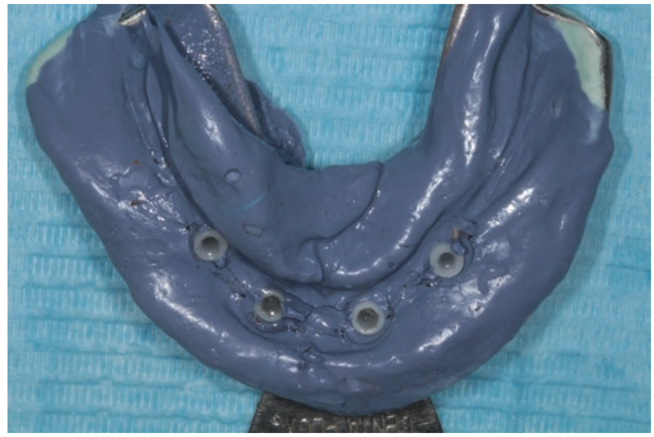

Fig. 8 Transfers remaining in the impression

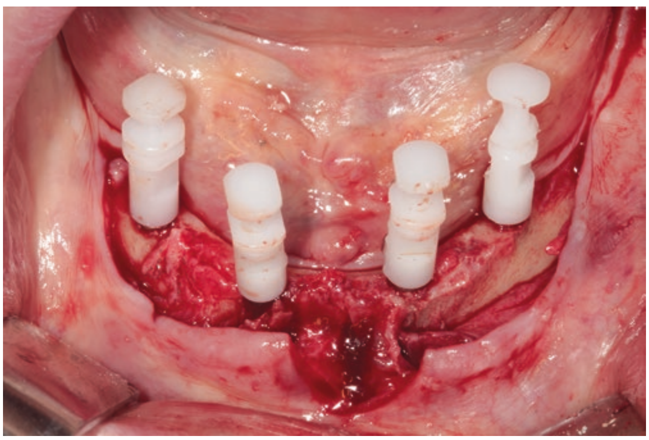

Fig. 7 Inserting the transfers

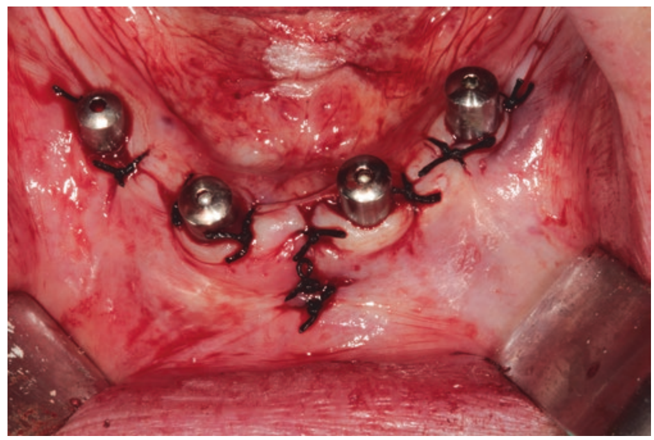

Fig. 9 Healing abutment placement

3 days, and in case of pain, analgesics can be taken as required.

Prosthetic Placement

The impression is sent to the laboratory to fabricate the retention bar and to finish the prosthesis, which by now, with the teeth set in wax, will be almost complete. Transepithelial abutments are placed on the model and the retention system is prepared on the abutments. Ideally, this should be a U-shaped Ackerman-type bar with polygonal support to minimize rotational movements, or non-axial forces on the implant; this will allow osseointegration to proceed normally. The literature describes immediate loading protocols using the Locator® system, which have obtained successful outcomes. Nevertheless, the advantages of the retention bar outlined above make it preferable to any other type of retention. When the impressions have been sent to the laboratory, the prosthesis should be ready within 48 h (Figs. 16 and 17).

When it arrives at the clinic, the healing abutments are unscrewed, and the bar is checked for fit. This can be fixed directly to the implants, or preferably base abutments (Prounic-plus) can be placed on the implants to which the bar is screwed, applying the torque recommended for the particular system (Figs. 10, 11, 12, and 13).

In cases in which the fit is inadequate, the bar can be cut, splinting it with acrylic and returning it to the laboratory for soldering, or the impression process can be repeated.

Lastly, the finished overdenture is placed and the patient is given instructions as to how to insert and remove the prosthesis and provided with information about general care and maintenance of the overdenture. Patients are advised to keep the prosthesis in place for the first 24 h in order to manage inflammation of the underlying mucosa (Fig. 14). The entire process is described schematically in Fig. 15.

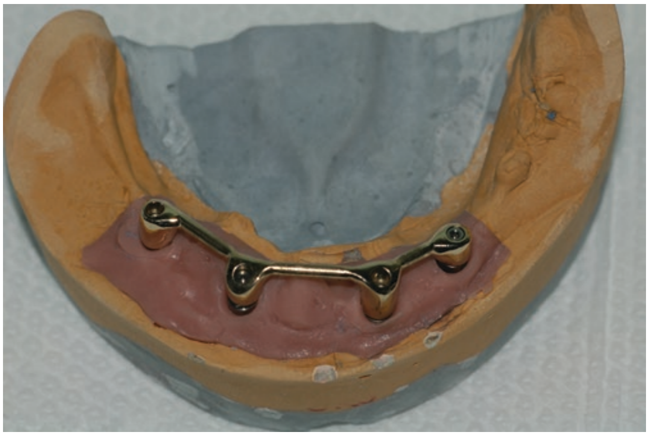

Fig. 10 Working model with retention bar

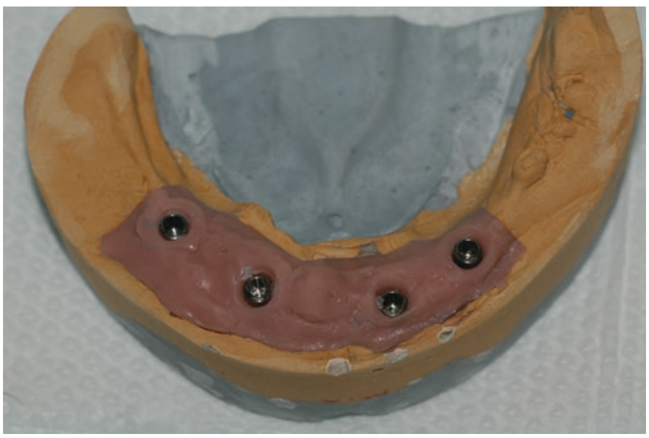

Fig. 11 Working model with implant analogues

Fig. 12 Clinical state of the mucosa 48 h after surgery

Follow-Up

A few days after prosthesis placement, and 8 or 10 days after implant surgery, the sutures are removed and healing is assessed. Clinical check-ups should begin 15 days after

Fig. 13 Placement of the bar on the implants

Fig. 14 Clinical image of the prosthesis in place

suture removal, checking the peri-implant mucosa and the overdenture fit. Thereafter, a regular follow-up schedule is arranged that will make it possible to detect possible complications in sufficient time to facilitate their treatment. Check-ups are recommended after 1, 3, 6, 9, 12, 18, and 24 months, checking the state of the mucosa and performing peri-implant probing (Figs. 16 and 17). Radiographic check-ups to assess bone response to immediate loading should be performed at least at the time of bar placement, after 6, 12, and 24 months and annually thereafter (Figs. 18, 19, and 20).

Results

Immediate loading of mandibular implant-supported overdentures is a highly predictable treatment that patients are requesting with increasing frequency as it avoids wearing a removable denture (without retention). Contrary to what might be imagined, the age of patients undergoing treatment is not all that old, being mostly around 65 years (Chen et al.

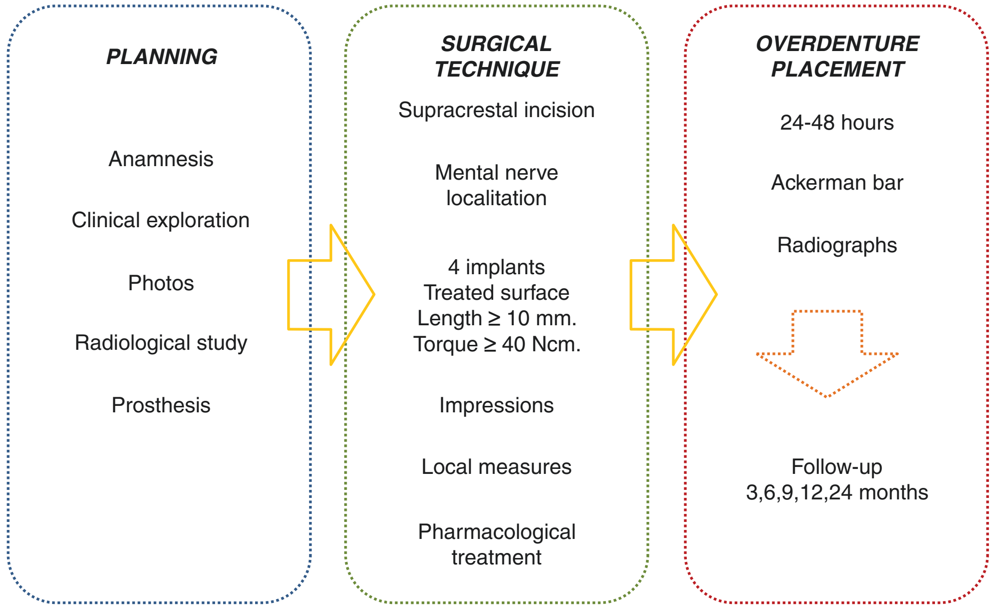

Fig. 15 Schema describing the entire mandibular immediate loading protocol

Fig. 16 Scheduled check-up: clinical image

Fig. 18 Patient presenting severe periodontal problems and retained upper canines

Fig. 17 Bacterial plaque retention on bar resulting from poor oral hygiene maintenance

Fig. 19 Rehabilitation with upper and lower overdentures (after 10 years)

Fig. 20 Follow-up radiology image, 15 years after surgery

2013). The main age group requesting prosthetic rehabilitation of the lower arch is the over-60s, who are less willing to undergo prolonged surgical procedures. In this context, rehabilitation supported by four intermentonian implants is a good therapeutic option, as the surgery involved is not very time-consuming, is cost-effective, and leaves the way open for future interventions, adding further implants in the posterior region and replacing the implant-retained prosthesis with a fixed prosthesis.

As stated at the beginning of this chapter, intermentonian bone quality is a factor that assists immediate loading. This anatomical area offers a Lekholm and Zarb bone classification value of D1–D2, which will produce higher implant stability quotient (ISQ) values than those obtained in the upper maxillary. In this context, Pieri et al. (2009) obtained a mean ISQ of 60.92 for 103 upper maxillary implants, lower than the mean mandibular ISQ value obtained by Monje et al. (2014).

For this type of rehabilitation, the number of implants, their location, distribution, and the retention system used are all key factors for ensuring implant survival. The use of four intermentonian implants is favored by the bone quality and quantity in this area, which, together with rigid splinting by a bar, reduces implant micromovement that might otherwise place osseointegration at risk and increases the success rate of this type of treatment.

So, when carrying out rehabilitation by means of immediately loaded implants, it is of fundamental importance to obtain good primary stability. Correct control of the forces applied (ISQ values) will prevent micromovement and maintain implant stability throughout the follow-up period, during which it may even increase.

Another key factor for the success of this treatment protocol is the implant surface treatment. The earlier use of flat or polished titanium as a key element for successful osseointegration has been succeeded by roughened surfaces (Sykaras et al. 1995). Current implant surfaces with textures created mainly by subtractive surface treatment allow a reduction in the time required before prosthetic loading.

Regarding the number of implants used for immediate loading in the edentulous mandible, the literature provides varied information, ranging from the insertion of one or two interforaminal implants to the placement of four splinted and immediately loaded implants. Single or pairs of interforaminal implants have been seen to obtain success rates between 88.4 and 100% after 12 months of functional loading (the reduced success rate could be due to the low insertion torque—lower than 40 Ncm at the moment of loading) (Liddelow and Henry 2010; Kronstrom et al. 2010). Four implants obtain a success rate of close to 100% after 12 months, and a peri-implant bone loss below 1 mm reported by most authors (Chiapasco et al. 2001; Romeo et al. 2002; Weischer et al. 2005; Chiapasco and Gatti 2003; Wittwer et al. 2007; Melo et al. 2009).

Another factor influencing the outcome of this type of treatment is the length of the implants, which should be over 10 mm to ensure high primary stability (Grunder et al. 1999; Martínez-González et al. 2013; Martín-Ares et al. 2016).

As for implant survival, various studies have obtained survival rates comparable to those of conventional loading protocols, close to 98% using implants with treated surfaces (Babbush et al. 1986; Spiekermann et al. 1995), and in one study with a 5-year follow-up, 100% (Henry et al. 1996). Peri-implant bone loss may increase slightly after 5 years but does not exceed values over 3 mm, regarded as pathological (Martínez-González et al. 2006; Hoeksema et al. 2016).

The most common complications with mandibular implant-supported overdentures occur in the prosthetic structure rather than the implants, in particular prosthetic fracture or worn retention clips that need replacing.

To sum up, satisfactory osseointegration will make immediately loaded mandibular overdentures a predictable therapeutic technique; this depends on an adequate diagnostic protocol, accompanied by correct surgical and prosthodontic procedures, followed by a long-term maintenance protocol.

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Part IV

Digital Workflow Approaches for Immediate Loading

Guided Surgery and Immediate Loading

Berta García-Mira

Abbreviations

CT	Computed tomography
CBCT	Cone beam computed tomography
SLA	Stereolithography
SLS	Selective laser sintering

Take-Home Message

Computer-guided (static) surgery is defined as the use of a static surgical template that reproduces virtual implant position directly from computerized tomographic data and does not allow intraoperative modification of implant position.

Technological advances have influenced the approach to implant treatment; one of the fields presently experiencing rapid development is computer-assisted implant dentistry.

With the development of software and digital workflows allowing for the planning and manufacturing of a surgical guide, a preformed provisional prosthesis can be inserted immediately after the implant surgery step.

It is now possible to pre-surgically determine with a high degree of accuracy and with 3D views the best position for implant placement and to plan the implant position and inclination, based on the final prosthetic outcome.

Potential errors, which are additive, can be found in each step in the CT-guided surgery workflow.

Deviation of the virtual plan of few degrees can prevent a perfect passive fit of the bridge.

The accuracy of guided implant surgery is determined by the sum of possible errors occurring during all steps of the procedure from implant planning over implant installation to prosthodontic reconstruction.

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General Considerations

Technological advances have influenced the approach to implant treatment. One of the fields presently experiencing rapid development is computer-assisted implant dentistry which can contribute for a better treatment planning, for the implementation of the implant placement, for capturing the intraoral situation, for processing data to design temporary and final prostheses, and for the manufacturing of prosthetic components (Hämmerle et al. 2009).

Moreover, the growing interest in minimally invasive surgery, together with the possibility of fitting prostheses with immediate function, has led to the development of software and digital workflows allowing for the planning and manufacturing of a surgical guide and provisional prosthesis that can be inserted immediately after the implant surgery step (Meloni et al. 2013a; D'haese et al. 2017).

The introduction and widespread use of cross-sectional imaging in implant dentistry using cone beam computed tomography (CBCT) over the last decade have enabled clinicians to diagnose and evaluate the jaws in three dimensions before and after insertion of dental implants, thus replacing computed tomography (CT) as the standard of care (Bornstein et al. 2014). Implant simulation software processes Digital Imaging and Communications in Medicine (DICOM) data obtained by CBCT and provides a preoperative view of the anatomical structures related to the future prosthodontics. Using adapted software, it becomes possible to plan the ideal implant position, taking into consideration tooth position as well as available bone. Therefore, it is now possible to pre-surgically determine with a high degree of accuracy and with 3D views the best position for implant placement and to plan the implant position and inclination, based on the final prosthetic outcome. This virtually planned implant position is transferred to the patient via the guiding system by a surgical template incorporating precision titanium sleeves (Tahmaseb et al. 2014). Moreover, stereolithographic models can be fabricated, and even the definitive prosthesis can be produced in a digital way.

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Moreover, delivering a fixed prosthesis on the same day of the extractions supported by immediate implants has become a major challenge. In the last year, some protocols explaining immediate loading of a full-arch restoration in fresh extraction sockets using computer-guided implant surgery have been published (Daas et al. 2015), but very low scientific evidence exists for their combination with immediate function, and there is a lack of homogeneity of the protocols.

Definition

In this chapter, static surgery will be treated and no dynamic methods will be developed. Computer-guided (static) surgery is defined as the use of a static surgical template that reproduces virtual implant position directly from computerized tomographic data and does not allow intraoperative modification of implant position (Hämmerle et al. 2009).

Digital technologies have been developed to aid in the flapless surgical procedure, but it is important to highlight that guided surgery may be performed with a flapless or raised flap approach, so in cases where there is a poor soft tissue attachment, modified flaps, miniflaps, and micro-flaps can be made. In MEDLINE, the concept of guided surgery procedure sometimes is associated with implants that are not fully guided placed. These implants are not placed through a surgical guide which reproduces virtual implant position and, therefore, cannot be considered as placed with guided surgery protocols. To more accurately compare research findings, the term "computer-guided surgery" (static) should be used to indicate only implant placement through surgical templates that does not allow intraoperative modification. In fact, Bencharit et al. (2018) proposed a cross-sectional study comparing fully and partially guided implant surgery in 16 partially edentulous patients requiring placement of 31 implants. They found that fully guided implant surgery was more accurate than partially guided implant surgery.

Advantages

By visualizing bone volume preoperatively, it may be possible to place implants more precisely in the available bone, with a consequent reduction in any grafting requirements. Computerized planning also helps to avoid anatomical structures. It might even allow for the provision of implant therapy where complex anatomical limitations had previously precluded treatment (Hämmerle et al. 2009).

Flapless implant surgery has generally been considered, regardless of surgical experience, as a blind procedure because of the difficulty in evaluating alveolar volume, which could increase the risk of perforating the cortical plates, dehiscences, and/or adjacent teeth (Van de Velde et al. 2008). This finding suggests that when using freehand flapless surgery, additional guidance during preparation of the implant bed and during implant placement is required specially in extensive multiple implant cases. This holds especially true in edentulous jaws where landmarks for proper implant positioning are missing. Actually, with computer-guided surgery, the flapless technique could be guided improving the results and minimizing the complications of this technique (Arisan et al. 2010). Therefore, other advantage in guided surgery is the possibility of operating with a minimally invasive approach (without flap elevation) which has been associated with minimal bleeding, no need for sutures, shorter surgical time, and a reduction of patient morbidity. Nevertheless, guided surgery may be performed with a flapless or raised flap approach. In fact, most of the studies published about guided surgery do not described detailed clinical information on peri-implant tissues, and there is a scientific need to sustain the usage of flapless-guided surgery.

Moreover, computer-aided design and computer-assisted manufacturing technology opened the possibility for preoperative planning and proper communication with the patient, surgeon, prosthodontist, and dental technician (Marchack and Moy 2014). In time, these systems might have the potential as teaching tools.

In addition, a prefabricated restoration could be delivered immediately after implant placement to improve patient satisfaction and self-perceived factors related to comfort, function, and esthetics. Finally, increased surgical precision may lead to improvements in implant survival rates. Its widespread adoption, however, remains to be seen due to a steep learning curve, time involved, and financial considerations (Orentlicher et al. 2014).

Clinical Recommendations

Computer-guided surgery may optimize several treatment processes, and with appropriate training, experience, and pre-surgical planning, could be useful in situations where there is complex anatomy and where minimal invasive surgery is desirable. They can also be used for the optimization of implant placement in critical esthetic cases (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13,

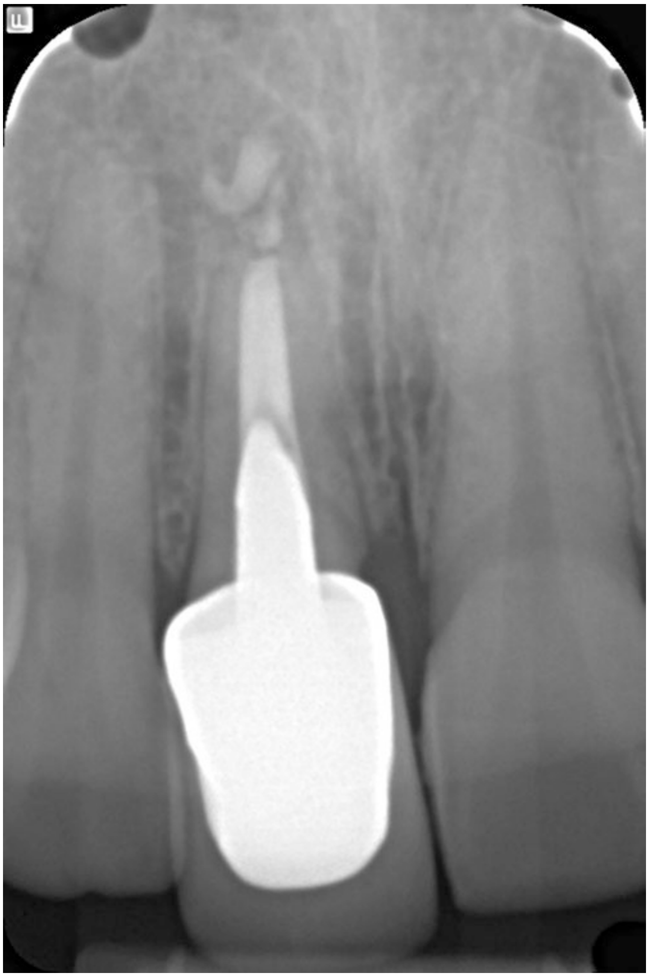


Fig. 1 A 35-year-old patient with no medical history of interest who attended the consultation for the fracture of a 1.1. In the clinical and radiographic exploration, the root of the fractured 1.1 and the good health of the soft tissues are observed. There are no signs or symptoms of infection. Being an esthetical compromised area, it was decided to perform the extraction of the 1.1 and make a bone ridge preservation and a connective tissue graft. At 5 months after the extraction, the implant placement and the restoration are planned with an immediate provisional prosthesis using guided surgery techniques. The planning was carried out using the 3 Diagnosys® computer system (3DIEMME, Cantu'CO, Italy), and the guided surgery system Echo PLAN (Sweden & Martina, Padua, Italy) was used for the subsequent placement of a PRAMA implant (Sweden & Martina, Padua, Italy). Image of the intraoral radiography prior to the extraction of 1.1 where the horizontal fracture of the root is observed

Fig. 2 After 5 months of the extraction and the bone ridge preservation, the placement of an implant in the 1.1 is planned using guided surgery. Frontal clinical image, the distal papilla of 1.1 is located more cervical than the mesial papilla and the contralateral papilla

Fig. 3 Occlusal image, a slight resorption of the alveolar crest is observed in the vestibular area of the tooth

Fig. 4 In order to carry out the planning in the software, an EVOBITE bite guide (3DIEMME, Cantu'CO, Italy) is used, and CT scan is performed to obtain the images in DICOM format. CT image

Fig. 5 In the CT scan, the alveolus is observed after 5 months of the alveolar preservation, and the vestibular cortical bone has been maintained

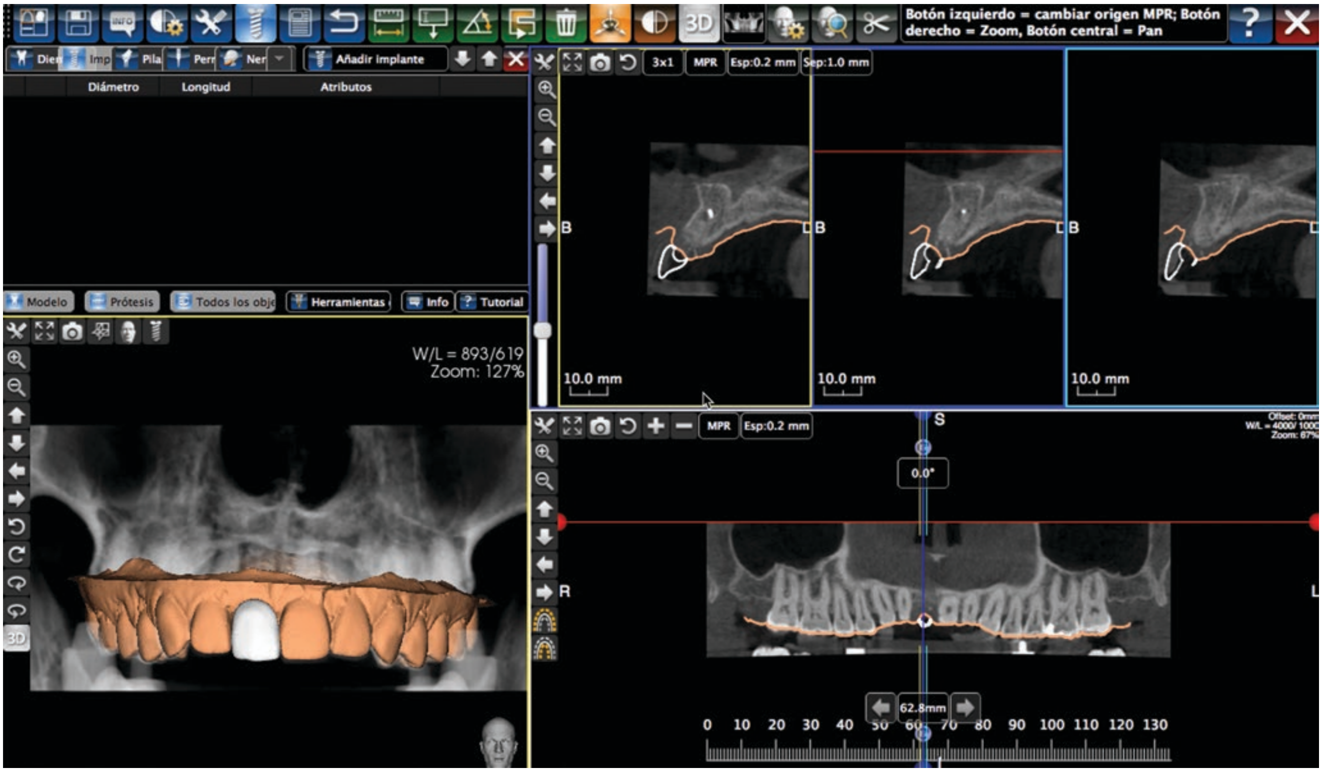


Fig. 6 Using the computer system 3 Diagnosys® (3DIEMME, Cantu'CO, Italy), the placement of an implant in the position of 1.1 is planned

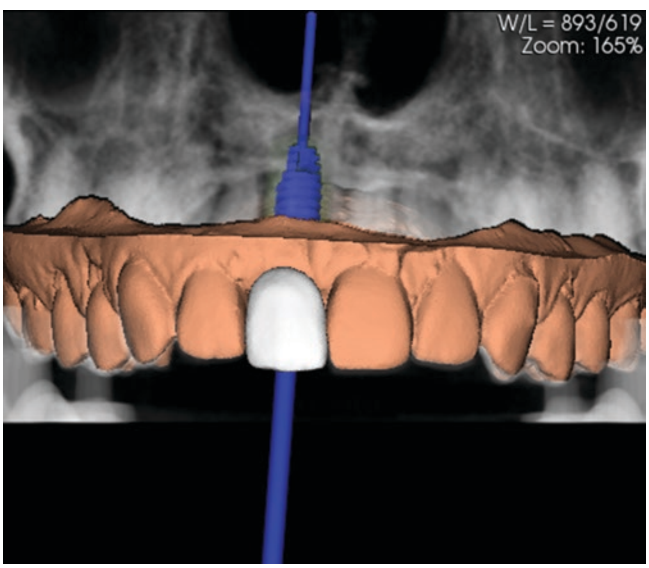


Fig. 7 After introducing the diagnostic waxup of the prosthetic restoration, the placement of a PRAMA implant of 4.25 mm in diameter and 11.5 mm in length is planned (Sweden & Martina, Padua, Italy)

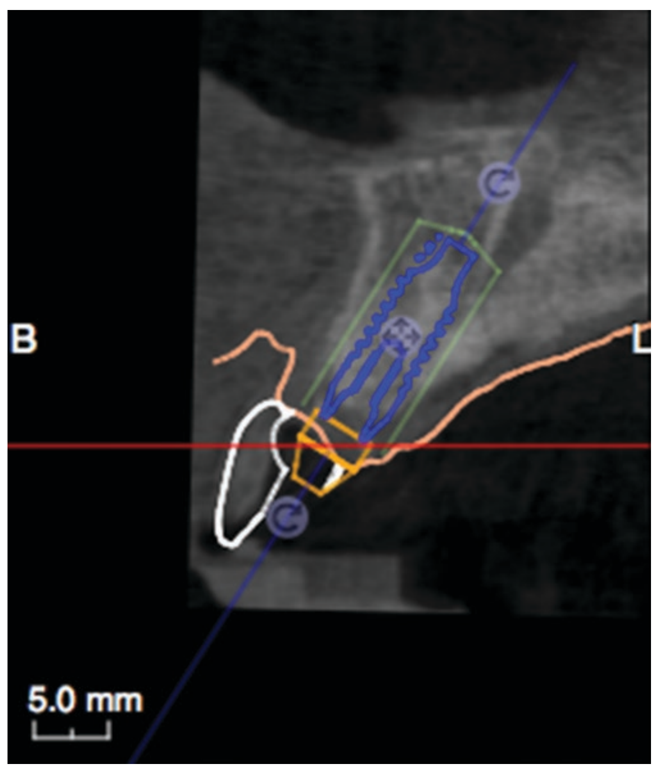


Fig. 8 Lateral image after doing the planification: the software allows placing the implant and checking the correct prosthetic emergency and angulation

Fig. 9 The surgical splint is made using the PlastyCAD system (3DIEMME, Cantu'CO, Italy), and its adjustment is checked in the mouth

Fig. 10 To preserve the vestibular soft tissues and the keratinized gingiva, the circular scalpel of the surgical box is marked with a blue pencil and is taken as a reference. A miniflap is design in order to preserve this soft tissue

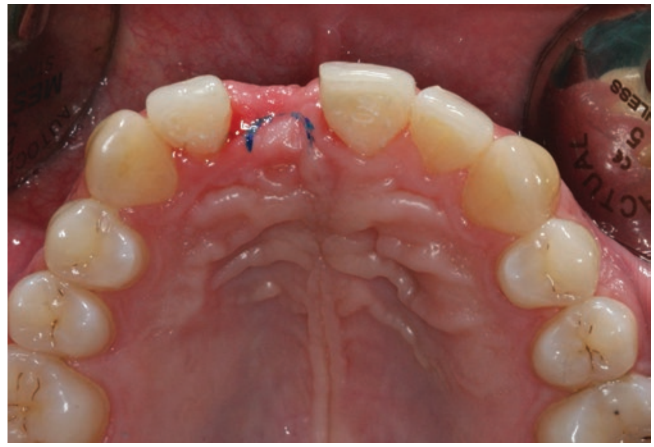


Fig. 11 Occlusal image after marking the soft tissue with the circular scalpel

Fig. 12 The surgical sequence of the guided surgery system Echo PLAN (Sweden & Martina, Padua, Italy) is used to drill; image of the first drill

Fig. 13 The last drill of the surgical sequence to place an implant of 4.25 mm in diameter

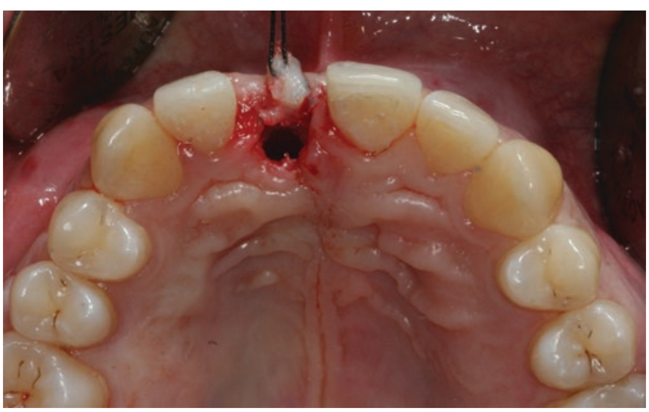


Fig. 14 The guide is removed in order to check the drilling procedure. The image shows the miniflap that has been pushed to the vestibular area in order to preserve the keratinized soft tissues

14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, and 41) and for immediate loading with preformed restorations (Hämmerle et al. 2015).

Fig. 15 The guided surgery abutment is screwed onto the PRAMA implant (Sweden & Martina, Padua, Italy), and the implant is guided completely through the guide with the angulation and the depth following the previous planification

Indications for guided surgery also include to aid in treatment planning and to improve patient understanding of therapeutic needs and treatment options (Bornstein et al. 2014).

In 2009 Katsoulis et al. (2009) analyzed computer-assisted diagnostics and virtual implant planning and evaluated the indication for template-guided flapless surgery and immediate loading in the rehabilitation of the edentulous maxilla. In the maxilla, advanced atrophy is often observed, and implant placement becomes difficult. Thus, for the authors, flapless surgery or an immediate loading protocol can be performed just in a selected number of patients, and a protocol that combines a computer-guided technique with

Fig. 16 Placement of the implant through the surgery guide

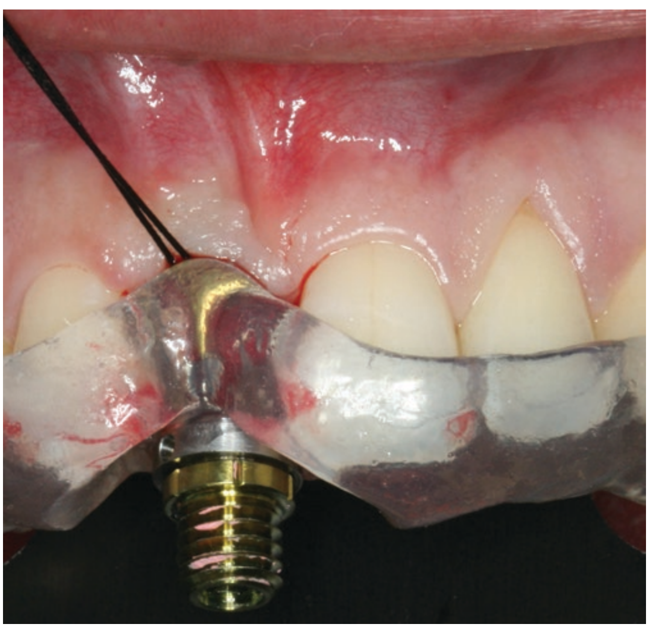


Fig. 17 Intraoperative image

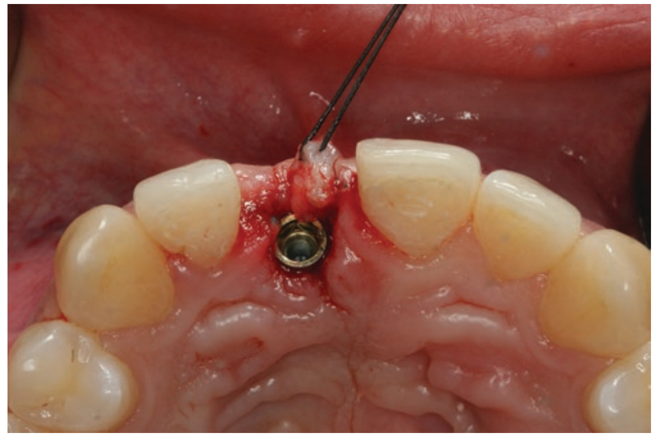


Fig. 18 Occlusal image after PRAMA implant placement

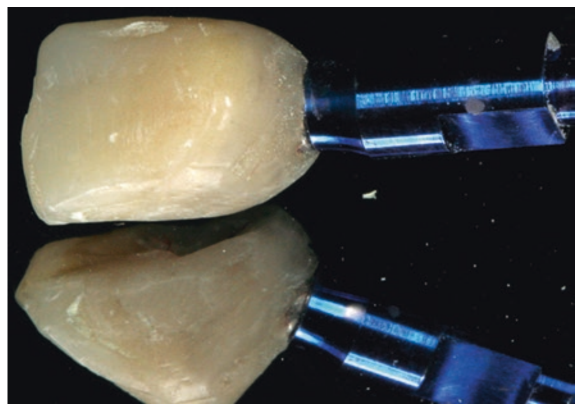


Fig. 19 Before placing a nonfunctional immediate crown it is verified that the Ostell® value is greater than 60. The BOPT prosthetic abutment is screwed onto the implant with its fixation screw, protected with a rubber, and resin is used. Image of the provisional crown

Fig. 20 Frontal image after the placement of the temporary prosthesis

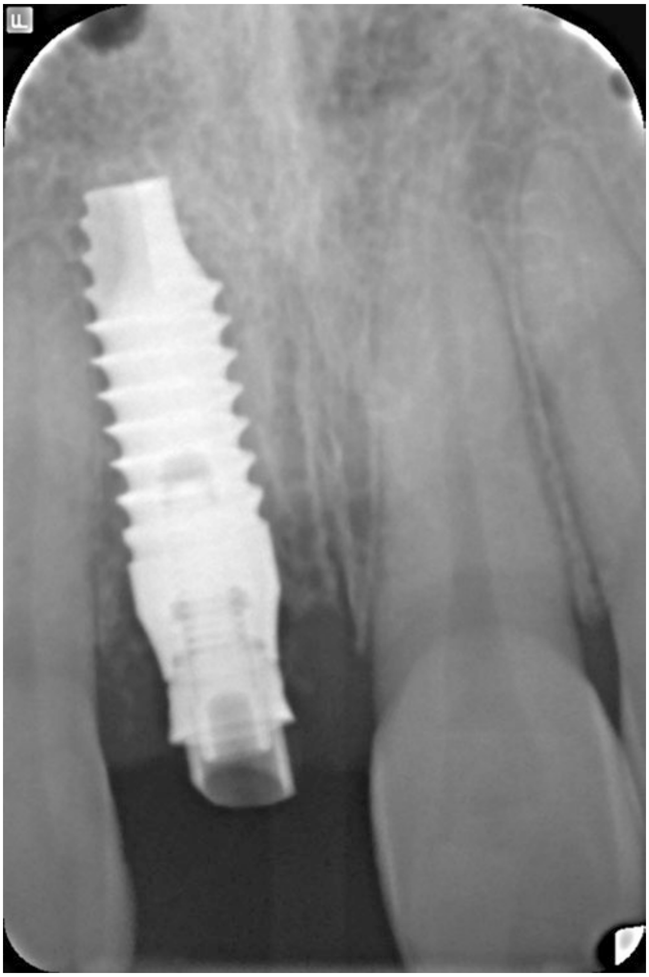


Fig. 21 Intraoral radiograph after surgery

Fig. 23 For the management of the emergence profile and to improve the esthetics, a new temporary screw-retained crown is made

Fig. 24 Frontal image after the placement of the new provisional: the good condition of the vestibular soft tissues is observed

Fig. 22 At 5 weeks after surgery, the good condition of the soft tissues is appreciated

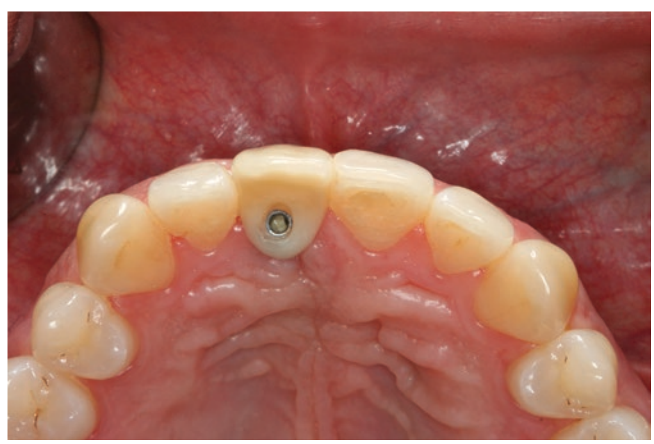


Fig. 25 Occlusal image

Fig. 26 After 4 months, soft tissues are stable and the final impressions are taken

Fig. 27 Definitive CAD-CAM crown is designed. Image of the abutment

Fig. 28 Occlusal image after the placement of the abutment: if we compare this image with the preparatory one, it is observed how the contour of the soft tissues has improved

Fig. 29 BOPT (Biologically Oriented Preparation Technique) crown is designed

Fig. 30 The crown is cemented on the implant, and the controlled compression on the soft tissues is observed

Fig. 31 Lateral image after cementation

Fig. 32 One month after the placement of the final prosthesis, the good conditions of the soft tissues is appreciated

Fig. 33 Lateral image, the contour of the soft tissues is appreciated

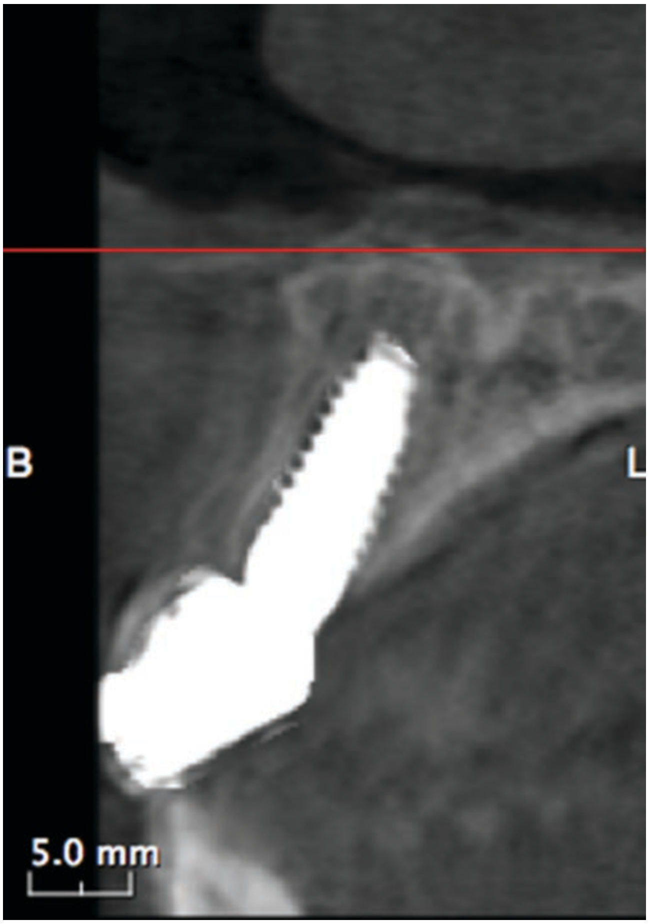


Fig. 34 At 12 months after implant placement, the correct emergence of the implant and the maintenance of the vestibular cortical bone are observed on CT scan

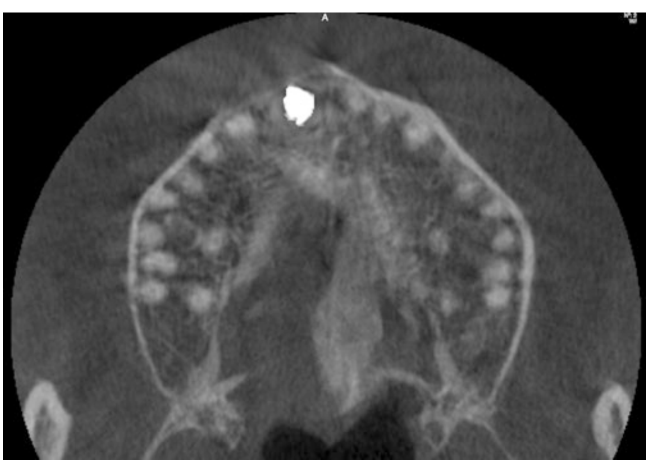


Fig. 35 In this image the maintenance of the vestibular cortical bone is confirmed

Fig. 36 Clinical image 12 months after placement

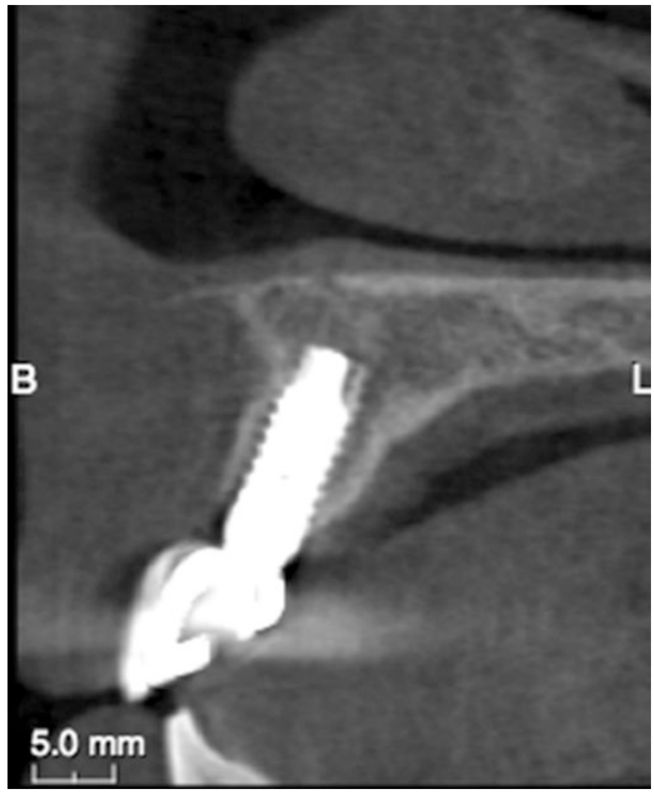


Fig. 37 CT scan at 36 months of follow-up where cortical bone maintenance is appreciated

Fig. 38 Axial CT image at 36 months of follow-up

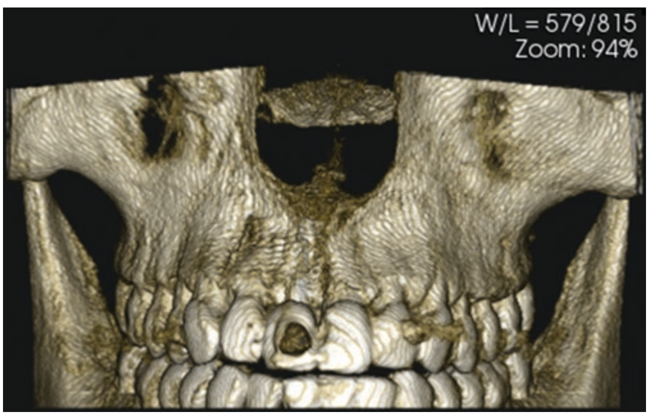


Fig. 39 3D reconstruction of the patient's DICOM

Fig. 40 Frontal image 36 months after placement. We also observe the gain in the soft tissues volume

Fig. 41 Lateral image at 36 months after placement

conventional surgical procedures becomes a promising option, which needs to be further evaluated and improved. For Pozzi et al. (2015), the combination of a guided, minimally invasive approach and tilted implants is an effective and biologically beneficial alternative to augmentation of the maxillary sinus floor (Figs. 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, and 83).

D'haese et al. (2013), after placing 114 implants with guided surgery and immediate loading in a partially or totally edentulous maxilla, 12 of those failures occurred in smokers, leading to 69.2% implant survival compared to 98.7% in nonsmokers. They suggested that smoking could be an exclusion factor when placing implants using stereolithography-guided surgery in conjunction with immediate loading.

Fig. 42 A 53-year-old patient who requests treatment with implants. The patient is diagnosed with advanced generalized periodontitis, and the maxillary teeth had to be extracted. Front image of the patient

Fig. 43 Orthopantomography after maxillary extractions

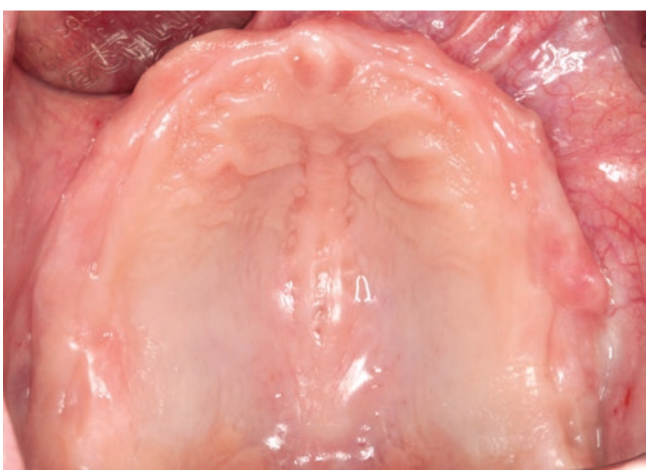


Fig. 44 Occlusal image of the maxilla

Fig. 45 After the diagnostic waxup, a radiographic guide is made

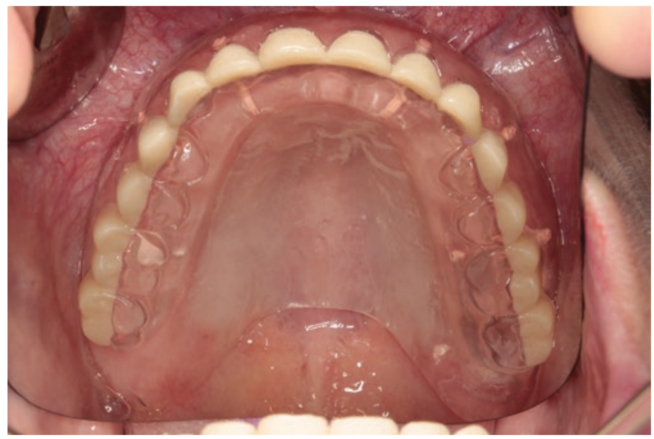


Fig. 46 Occlusal image of the radiographic guide

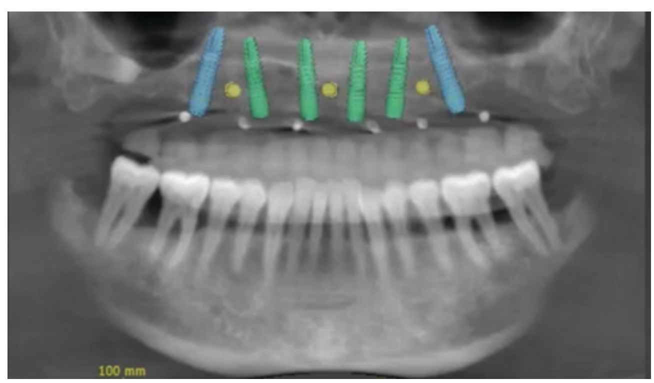


Fig. 47 After introducing all the data in the software, six maxillary PRAMA implants were planned (Sweden & Martina, Padua, Italy) using all-on-six design in order to avoid performing maxillary sinus floor elevation

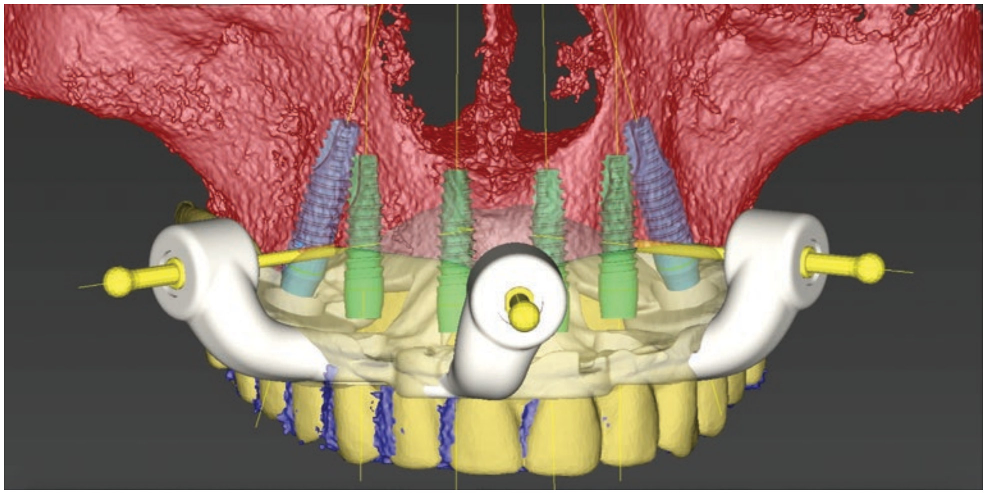


Fig. 48 Image of the software after designing the surgical guide

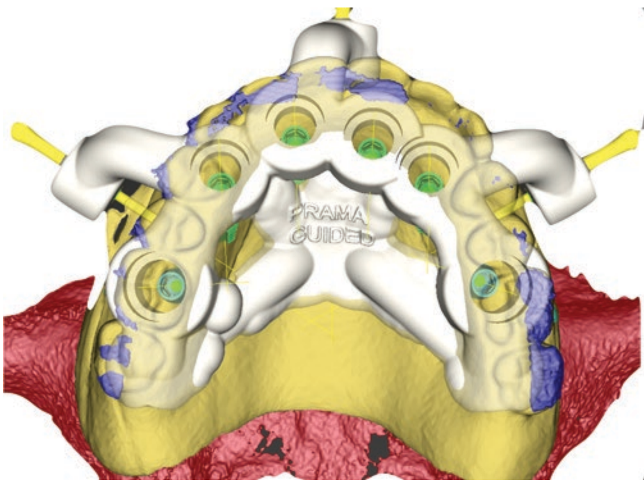


Fig. 49 Occlusal image of the planification

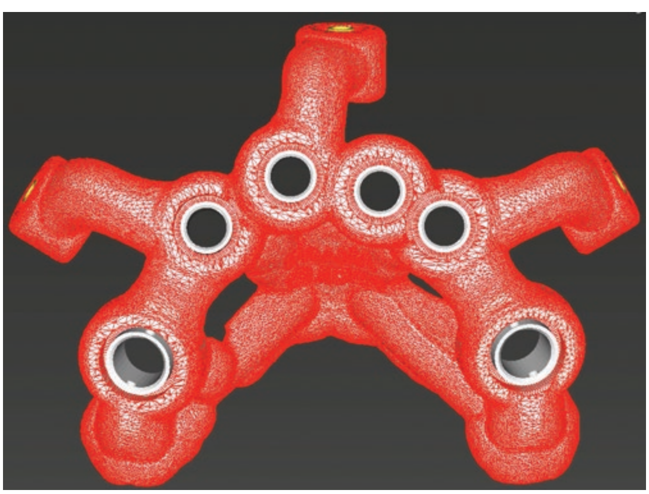


Fig. 50 Image of STL of the surgical guide

Fig. 51 Image of the surgical guide made by a 3D printer

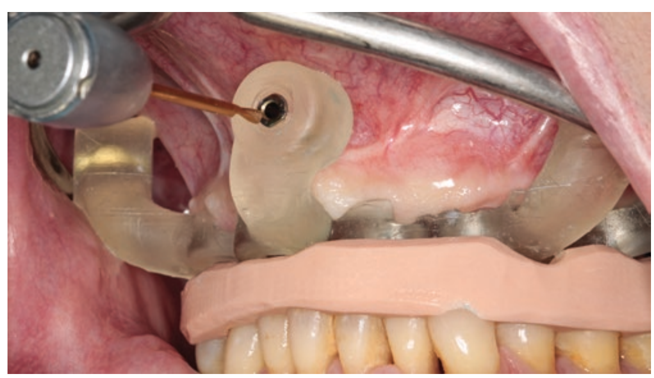


Fig. 52 The surgical guide is positioned in the mouth with the help of a silicone bite. We drill the cortical bone to place the fixation pins, which give great stability to the surgical guide

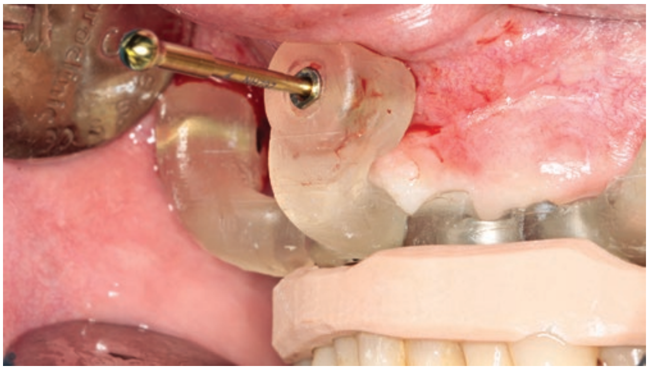


Fig. 53 Intraoperative image after placing the pins

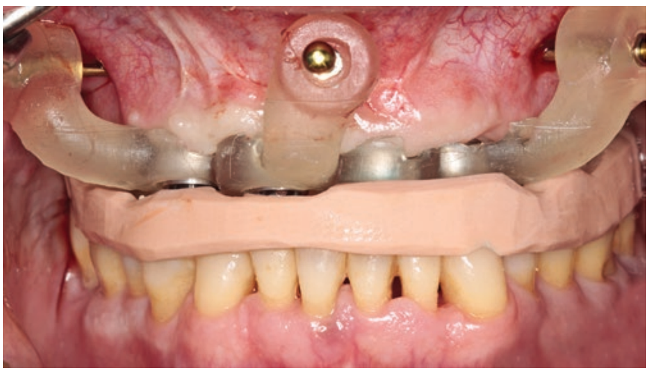


Fig. 54 The 3 pins have been place to increase the guide's stability

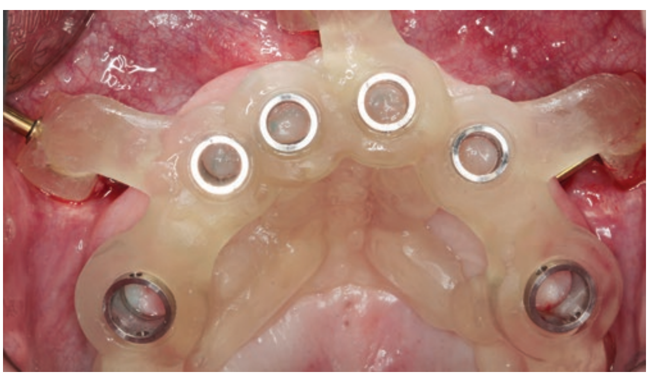


Fig. 55 Image once the surgical guide is stabilized

Fig. 56 With a punch drill, we eliminate the soft tissues

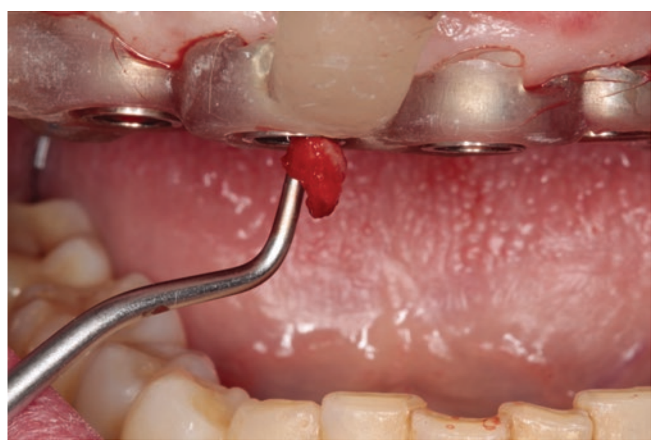


Fig. 57 With a punch bur, we eliminate the soft tissues

Fig. 58 Implant positions are drilled according to the indications of the industry

Fig. 59 Same procedure than in the anterior implants

Fig. 60 Drilling of the implant sites

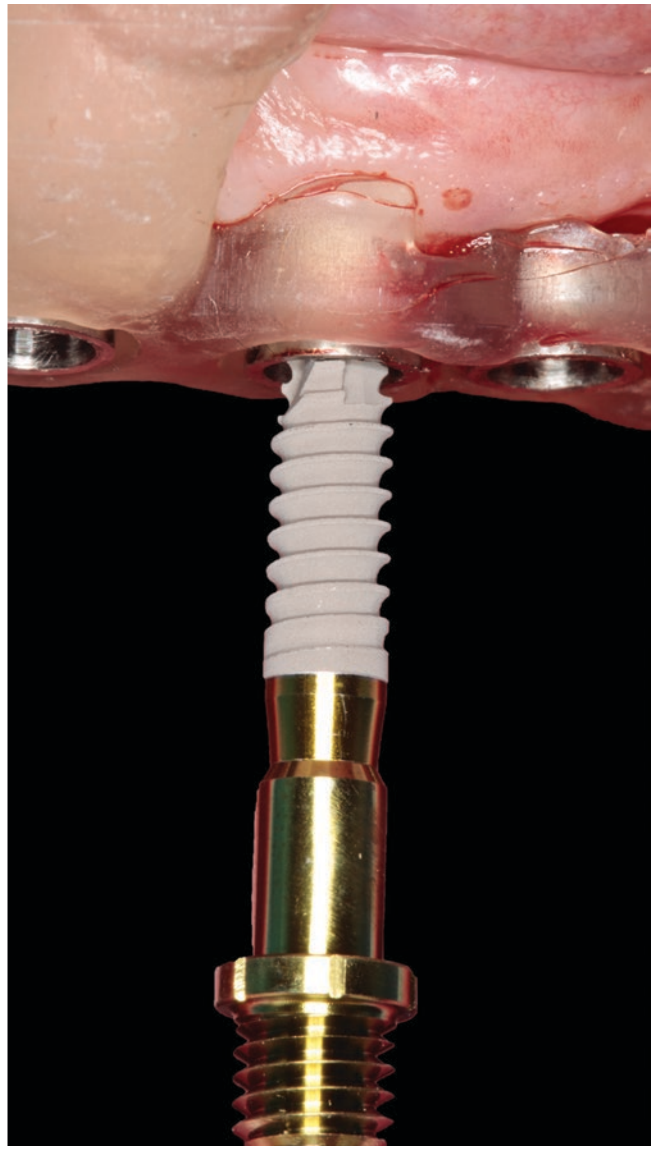


Fig. 61 The implants are placed through the surgical guide. The anterior implants are PRAMA implants of 3.8 mm × 13 mm

Fig. 62 The implants are placed through the surgical guide. PRAMA implants are 4.25 mm × 15 mm

Fig. 63 Occlusal image after implant's placement

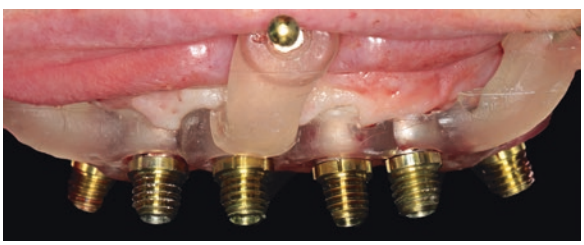


Fig. 64 Frontal image after implant's placement

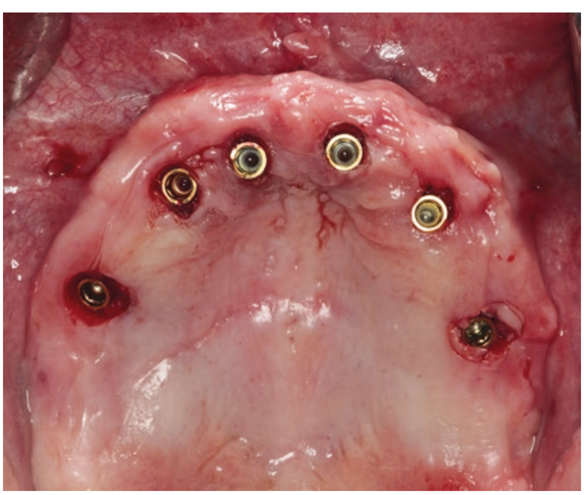


Fig. 65 Occlusal image after the removal of the surgical guide

Fig. 66 After measuring the Osstell values, in the most posterior implants, angulated abutments are placed, and then the provisional titanium abutments are placed over all implants. In the anterior implants, these provisional abutments are directly connected to the implants without using intermediate abutments

Fig. 67 The fit of the abutments are checked with an X-ray

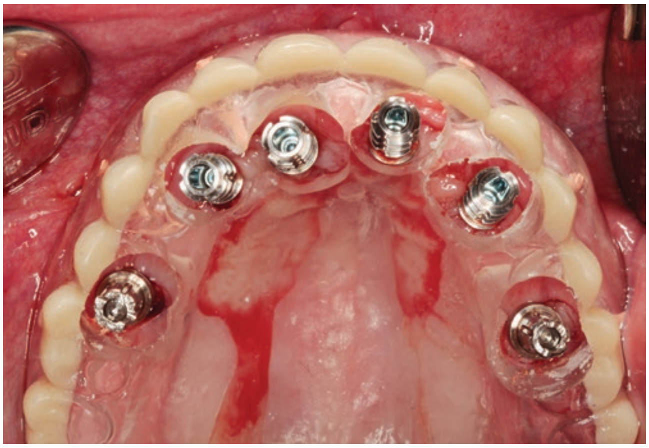


Fig. 68 Occlusal image after placing the abutments. The distal ones are trimmed to be able to take the impression in occlusion. We checked that the radiographic guide does not interfere with the abutments

Fig. 69 The abutments are splinted to the radiographic guide using Duralay resin

Fig. 70 The bite register is taken, and all the information is sent to the dental laboratory

Fig. 71 In the laboratory they place the analogs

Fig. 72 They fill with gum silicone

Fig. 73 The working model is obtained and placed in the articulator

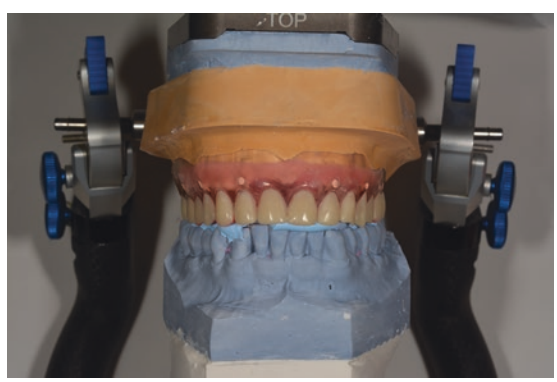


Fig. 74 Image of the articulator

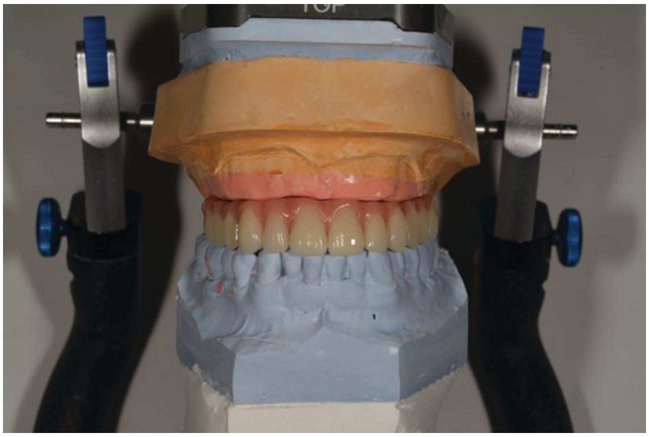


Fig. 75 The provisional fixed prosthesis is made

Fig. 76 Images of the temporary immediate loading prosthesis

Fig. 77 Images of the screw-retained loading prosthesis

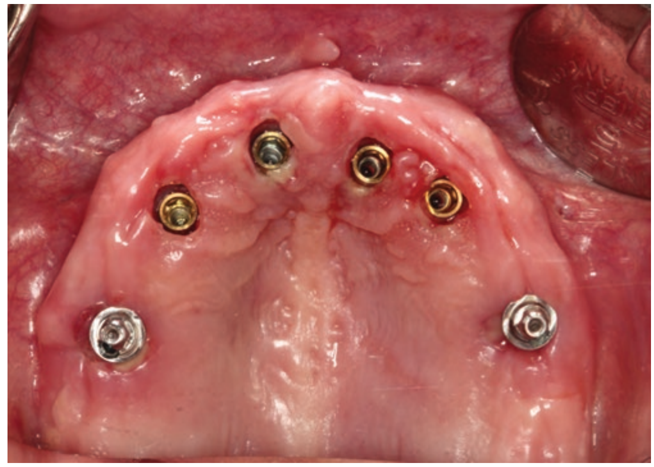


Fig. 78 Occlusal clinical image after the 48 postoperative hours

Fig. 79 Occlusal image after the placement of the prosthesis

Fig. 80 Frontal image where the good adjustment of the soft tissues is observed

Fig. 81 Orthopantomography image

Fig. 82 Extraoral picture

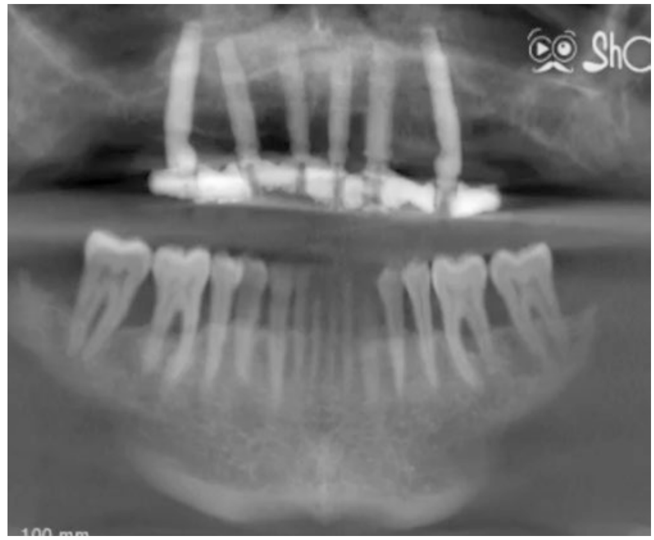


Fig. 83 Image of the postoperative CT

Pre-surgical Preparation

Although more data are now available, it is still difficult to compare reported treatment outcomes due to a number of factors, such as insufficiently defined preoperative parameters or the variety of therapeutic approaches. In addition, the impact of computer-guided software programs available in the market in treatment planning remains insufficiently defined.

Today, there are different systems on the market to guide the surgeon during the planning procedure and the placement of these implants. In the double scanning technique, a scanning is performed to the patient to get the DICOM images; afterward, a second CT scan (dual scan) is taken to the prosthesis only. The two scans are merged and superimposed on each other relating the denture to the patient's jaw. The resulting CT images are converted into a DICOM image and transformed into a three-dimensional virtual model where the surgeon will plan the implant positioning. The completed surgical plan is now sent, and the surgical template is fabricated. With this surgical template, the laboratory technician begins the fabrication of the master cast, the mounting of the newly master cast, the fabrication of the surgical bite registration (in edentulous patients), and in some cases the abutment selection and fabrication of the jig and ends with the fabrication of the provisional prosthesis (Bedrossian 2007).

For fabrication of the surgical template, stereolithography (SLA) and selective laser sintering (SLS) are currently in use. SLA uses an ultraviolet laser to successfully "laser cure" cross sections of a liquid resin. SLS uses a carbon dioxide laser to fuse together layers of a fine polyamide powder, and the models are opaque, whereas SLA models are translucent (Di Giacomo et al. 2012).

Surgical Procedure and Implant Placement

Most major implant manufacturers have created and marketed instrumentation for the fully guided placement of their implants. In some systems, a unique surgical template is used during all the drilling procedure, while in others for every specific diameter of implant drills required by the manufacturer, a different surgical guide was constructed (Van de Velde et al. 2010).

In a recent systematic review and meta-analysis, Raico Gallardo et al. (2017) compared the accuracy of computer-aided implant surgery when using different supporting tissues (tooth, mucosa, or bone). Eight clinical studies from the 1602 articles initially identified met the inclusion criteria for the qualitative analysis. The bone-supported guides showed a statistically significant greater deviation in angle ($P < 0.001$), entry point ($P = 0.01$), and apex ($P = 0.001$) when compared to the tooth-supported guides. Conversely, when only retrospective studies were analyzed, not significant differences are revealed in the deviation of the entry point and apex. The mucosa-supported guides indicated a statistically significant greater reduction in angle deviation ($P = 0.02$), deviation at the entry point ($P = 0.002$), and deviation at the apex ($P = 0.04$) when compared to the bone-supported guides. Between the mucosa- and tooth-supported guides, there were no statistically significant differences for any of the outcome measures. So, the authors concluded like in the fourth EAO Consensus Conference 2015 (Hämmerle et al. 2015) that bone-supported templates are less accurate than mucosa- and tooth-supported guides.

Usually, flapless implant surgery is performed in most of the published studies, but this technical procedure must be used only when well-preserved hard and soft tissues are present. Nevertheless, to preserve the keratinized mucosa, a small full-thickness flap can be raised (Figs. 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, and 111). A disadvantage of flapless-guided surgery is that discrimination between keratinized and nonkeratinized mucosa cannot be visualized on the implant planning software (Van de Velde et al. 2010). In cases with limited amounts of attached mucosa at implants sites, it is recommended to make small crestal- or palatal-oriented incisions pushing the tissues to the buccal side to avoid losing of keratinized mucosa more often caused by punching with the flapless procedure. A tissue grafting procedure can also be performed if needed (Tallarico et al. 2016). Maló et al. (2013) performed a study to test the hypothesis of the outcome of complete-arch flapless-guided implant surgery mandibular rehabilitations in the presence or absence of a residual band of keratinized mucosa <6 mm wide in the vestibular-lingual aspect, with and without a modification of the surgical protocol. The

Fig. 85 Image of the orthopantomography. Maxillary and mandibular atrophy is observed

Fig. 84 A 65-year-old patient with treatment with Adiro, who had two removable prostheses request treatment with implants. Lateral picture of the patient

Fig. 86 Thanks to the diagnostic waxup, the complete upper removable prosthesis and the transparent radiographic guide are obtained. The adjustment of both is checked in the mouth

Fig. 87 Clinical image of the radiographic guide in the mouth

Fig. 88 In order to make the superimposition of the DICOM format of the patient with the radiological splint, the EVOBITE bite was used to perform the patient's CBCT. Clinical image after adjusting the EVOBITE bite in the mouth

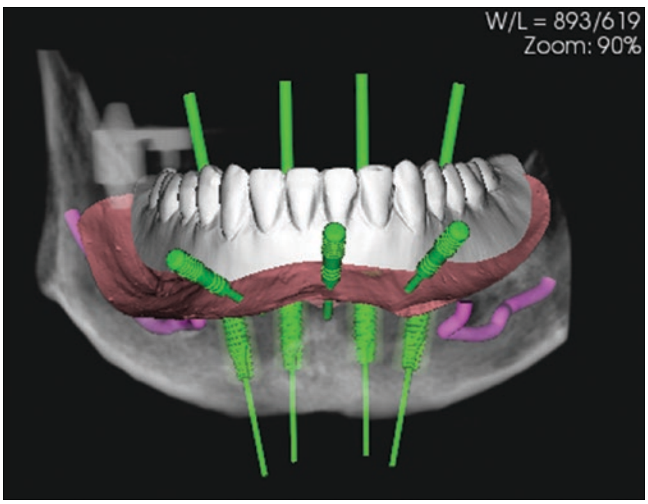


Fig. 89 All the information was introduced in 3Diemme planning system, and then four PRAMA implants (Sweden & Martina, Padova, Italy) 3.8 mm in diameter were planned following all-on-four technique. The anterior implants had a length of 11.5 mm and the distal implants of 13 mm. The software images show the superimposition of the soft tissues and the radiographic guide

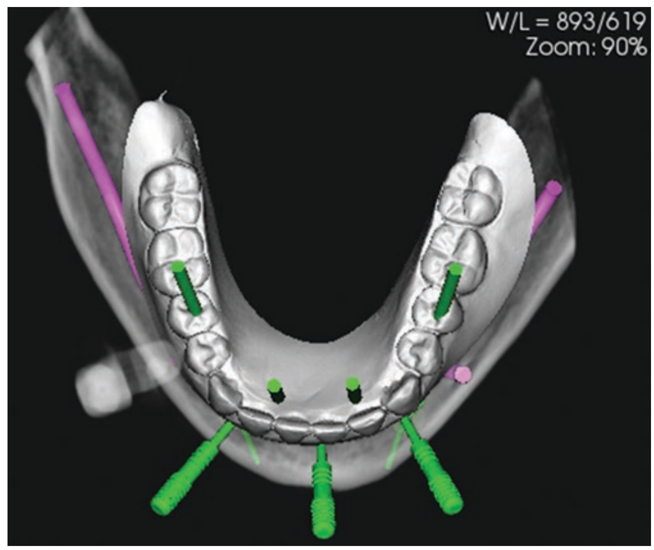
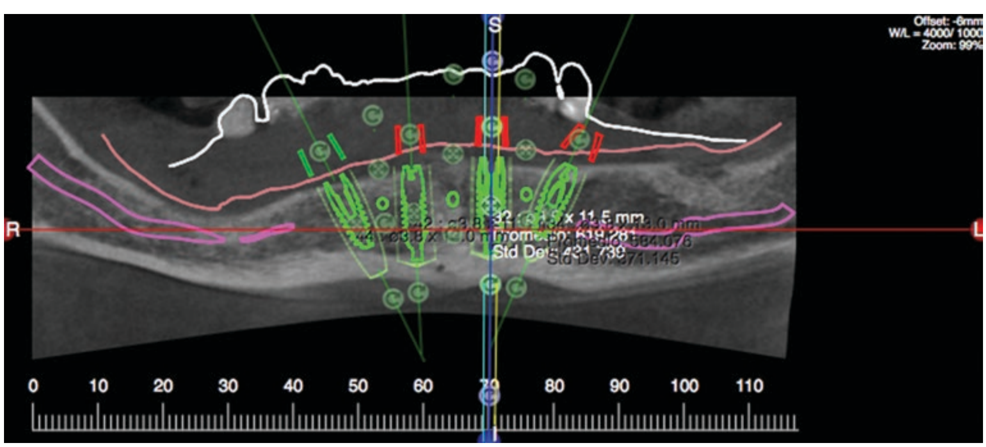


Fig. 90 Occlusal image of the planification

Fig. 91 Image of the software with the planification of the clinical case: note the characteristics of the implants



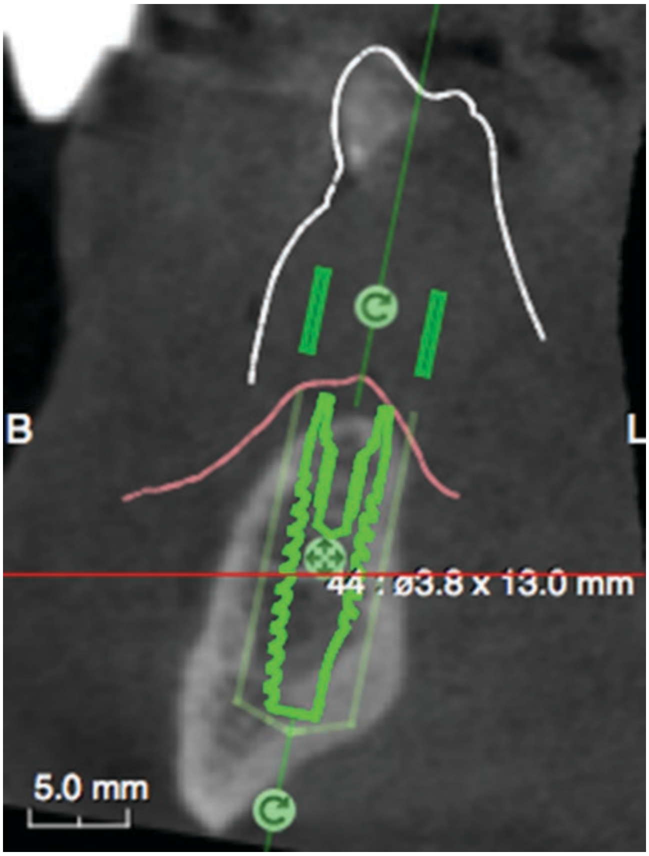


Fig. 92 Axial section of the 4.2 implant

modification of the protocol consisted in a flap opening to preserve keratinized mucosa. In 39 patients, with 156 implants, who were followed for 1 year, the absence of a residual band ≥6 mm in the vestibular-lingual aspect was significantly associated with clinical attachment loss and dehiscences.

Because standard water cooling is hindered, it is recommended to use an "in-out" drilling movement in order to cool the burs and to use an additional cooling between the guide and the operation site in order to prevent overheating (Marcelis et al. 2012). In addition, bone dust accumulates in

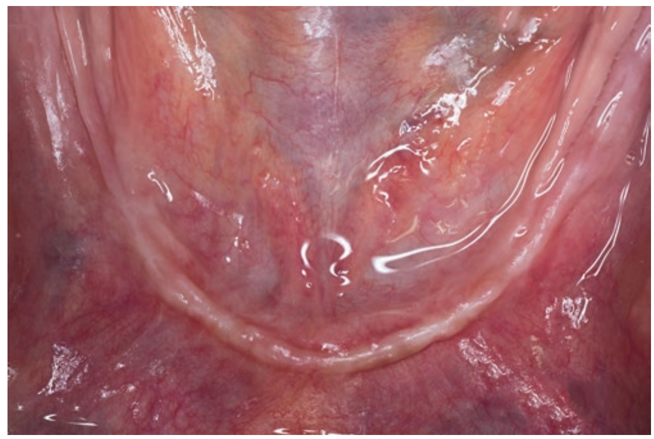


Fig. 94 Occlusal image of the jaw

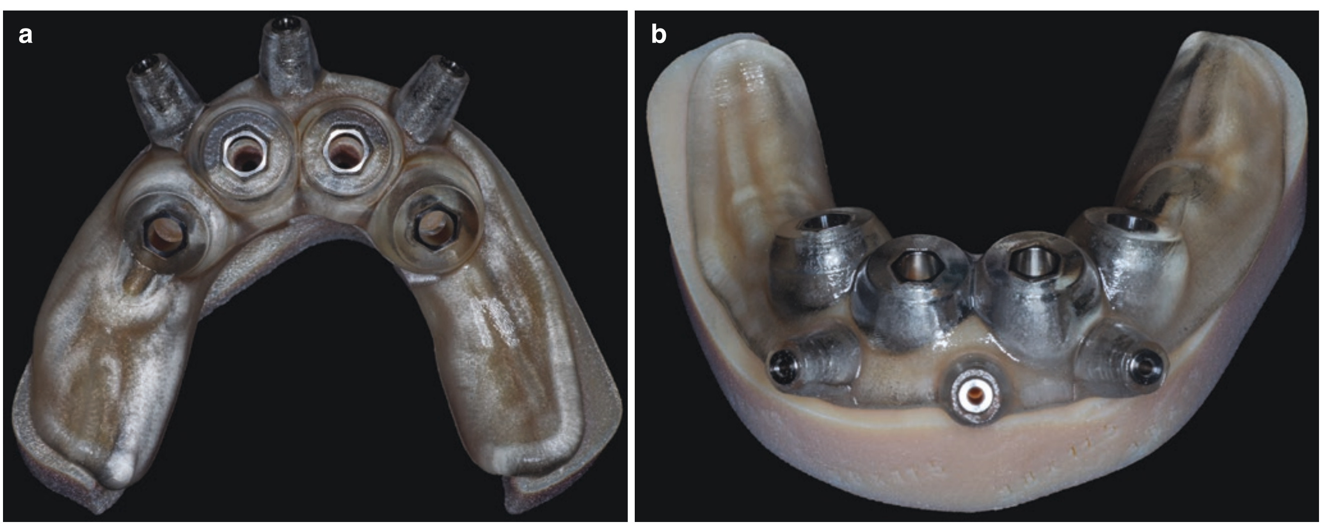


Fig. 93 (**a**, **b**) After planning with 3Diagnosis software (3Diemme,), the stereolithographic model and the surgical guide are made

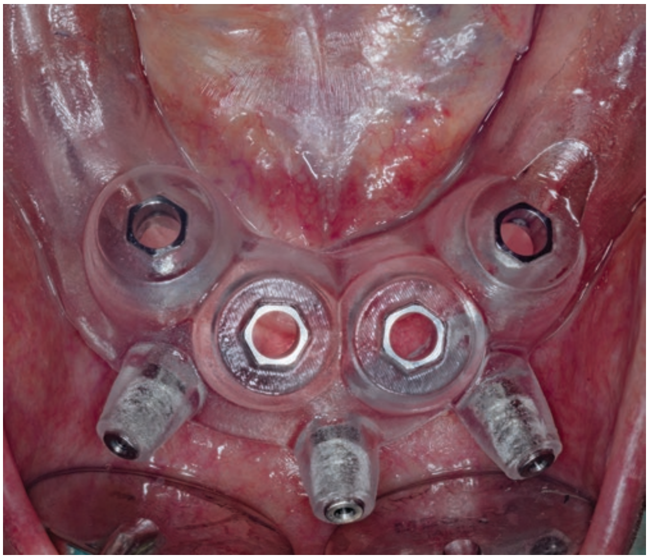


Fig. 95 We check the surgical guide

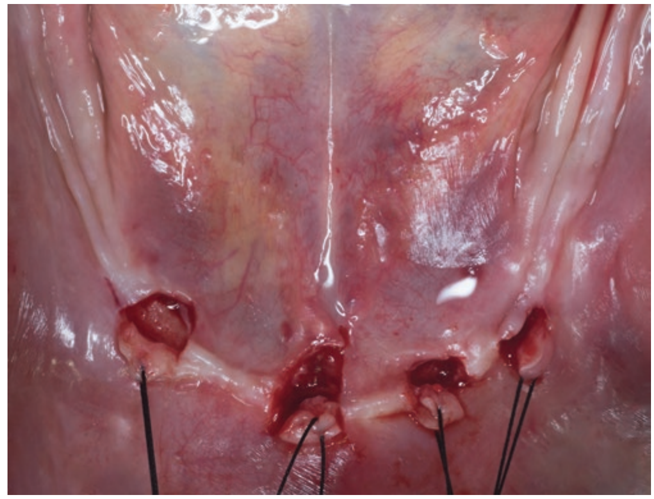


Fig. 97 Miniflaps were raised in order to avoid losing keratinized mucosa in the vestibular area of the implants

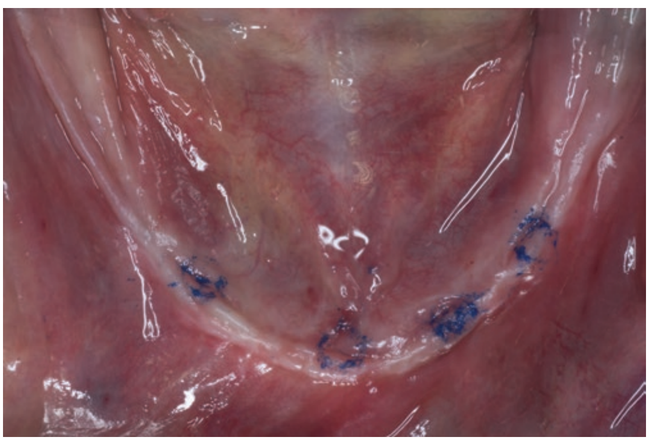


Fig. 96 Occlusal image after marking the implant positions

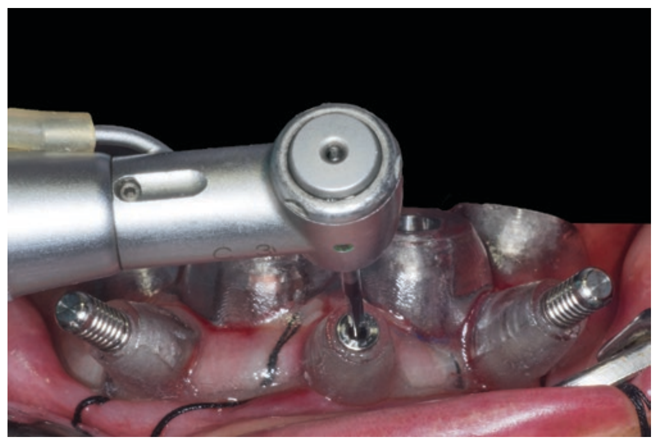


Fig. 98 The surgical guide is stabilized in the mouth with the help of three vestibular pins

the flutes of the drills. Hence, it is important to remove the drills from the drill guide during the preparation and have the osteotomy sites well irrigated (Yong and Moy 2008).

Moreover, in most studies implants are placed in healed bone. But the increasing demand for patients to have a smooth transition from a hopeless dentition to a fixed implant-supported prosthesis, without wearing an interim removable denture, raises new challenges to adapt these CAD-CAM techniques to immediate insertion in post-extraction cases. A step-by-step technique for the fabrication of a two-piece radiographic guide lets the patient to retain hopeless teeth during the diagnostic phases until the day of the surgery and allows for a prosthetically driven virtual planning of the implants to be inserted, independently from the position of the teeth to be extracted (Polizzi and Cantoni 2015).

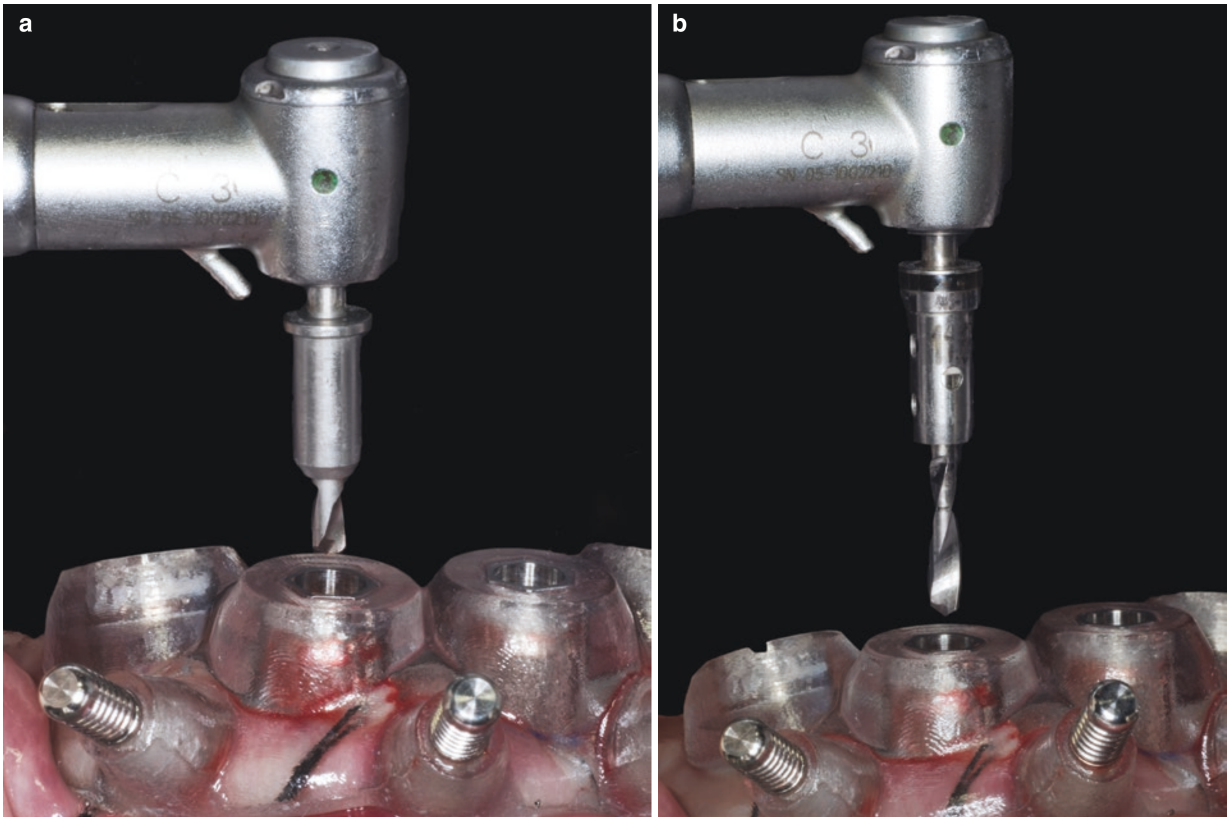


Fig. 99 (**a**, **b**) The Echo Plan drilling sequence from Sweden & Martina is used

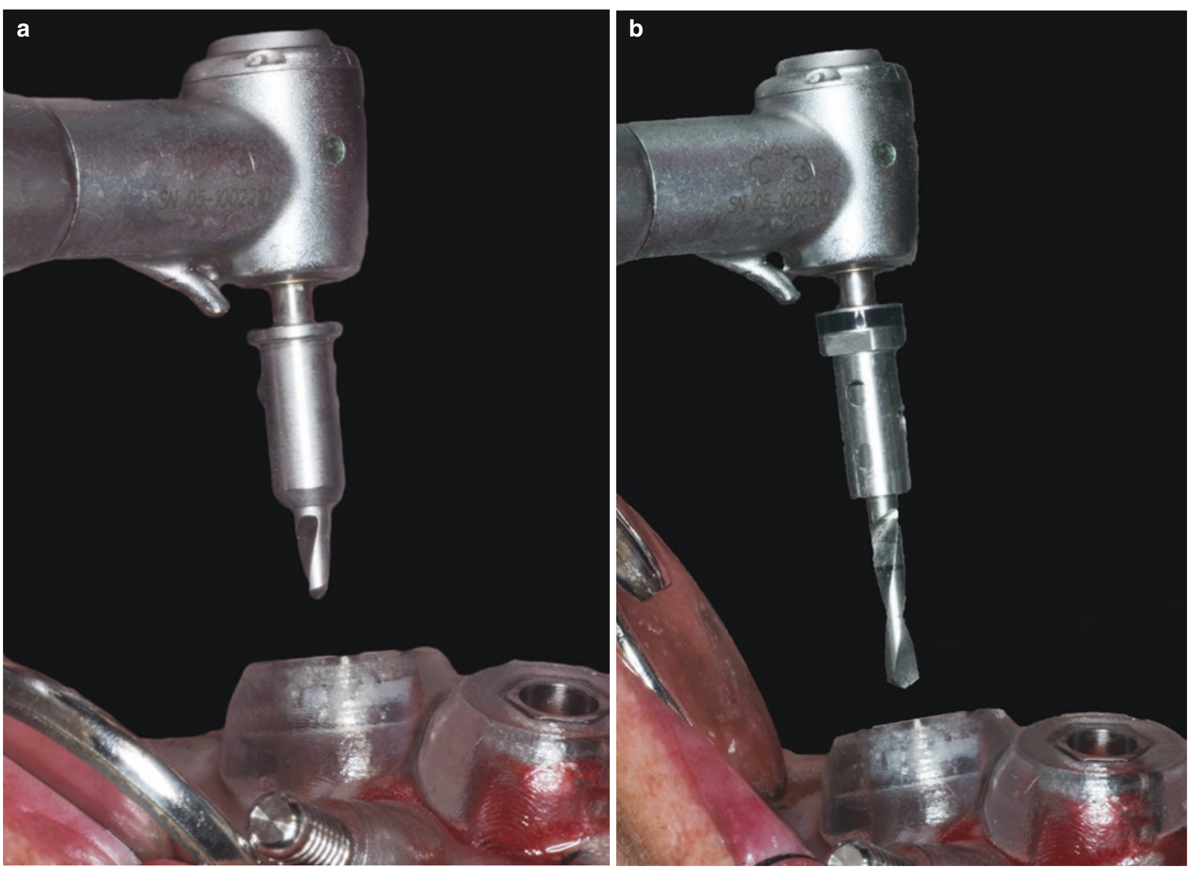


Fig. 100 (**a**) Drilling of the tilted implant with the cortical drill. (**b**) Another drill is used to drill the tilted implant

Fig. 101 Placement of the tilted implant through the surgical splint

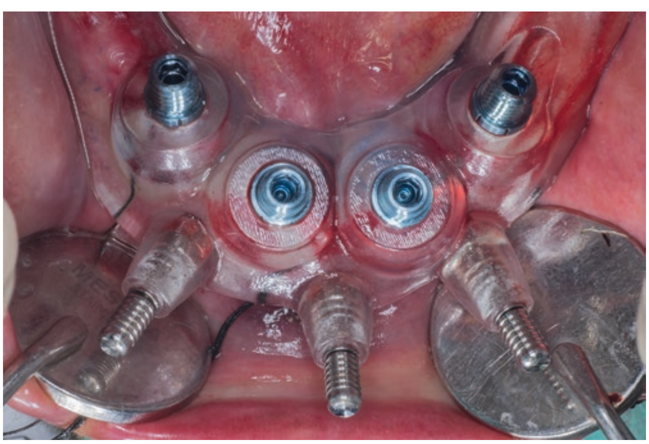


Fig. 102 Occlusal image of the surgical guide with the placement of the four guided implants

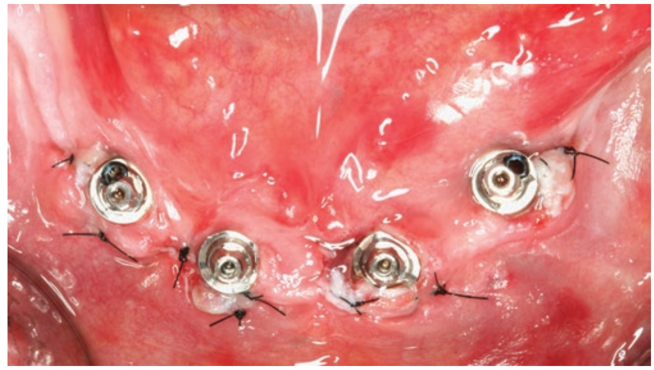


Fig. 103 After removing the surgical guide, intermediate abutments are placed in the four implants. The miniflaps are sutured

Fig. 104 Provisional titanium abutments were placed and checked with an X-ray

Fig. 105 The perforated radiographic guide is placed, and provisional titanium abutments are splinted using Duralay resin

Fig. 106 A bite register is taken

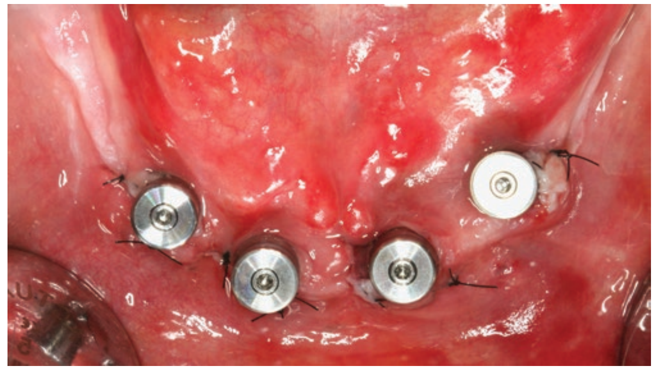


Fig. 107 While the laboratory manufactures the immediate loading prosthesis, PADs are placed over the abutments

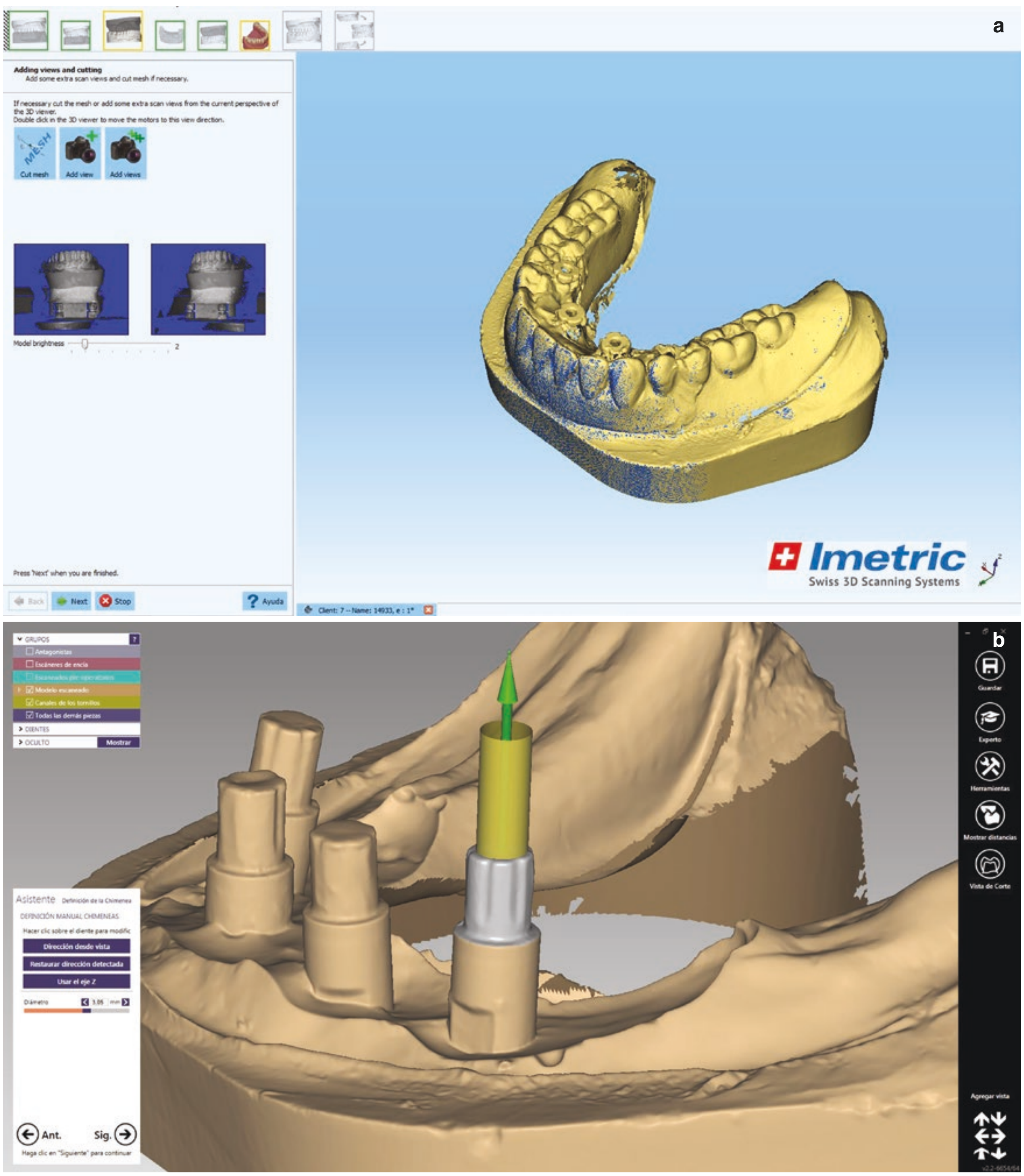


Fig. 108 (**a**) Digital model of the radiographic guide and titanium abutments in order to design a screw CAD-CAM prosthesis. (**b**) Design of the emergence profile of one of the implants

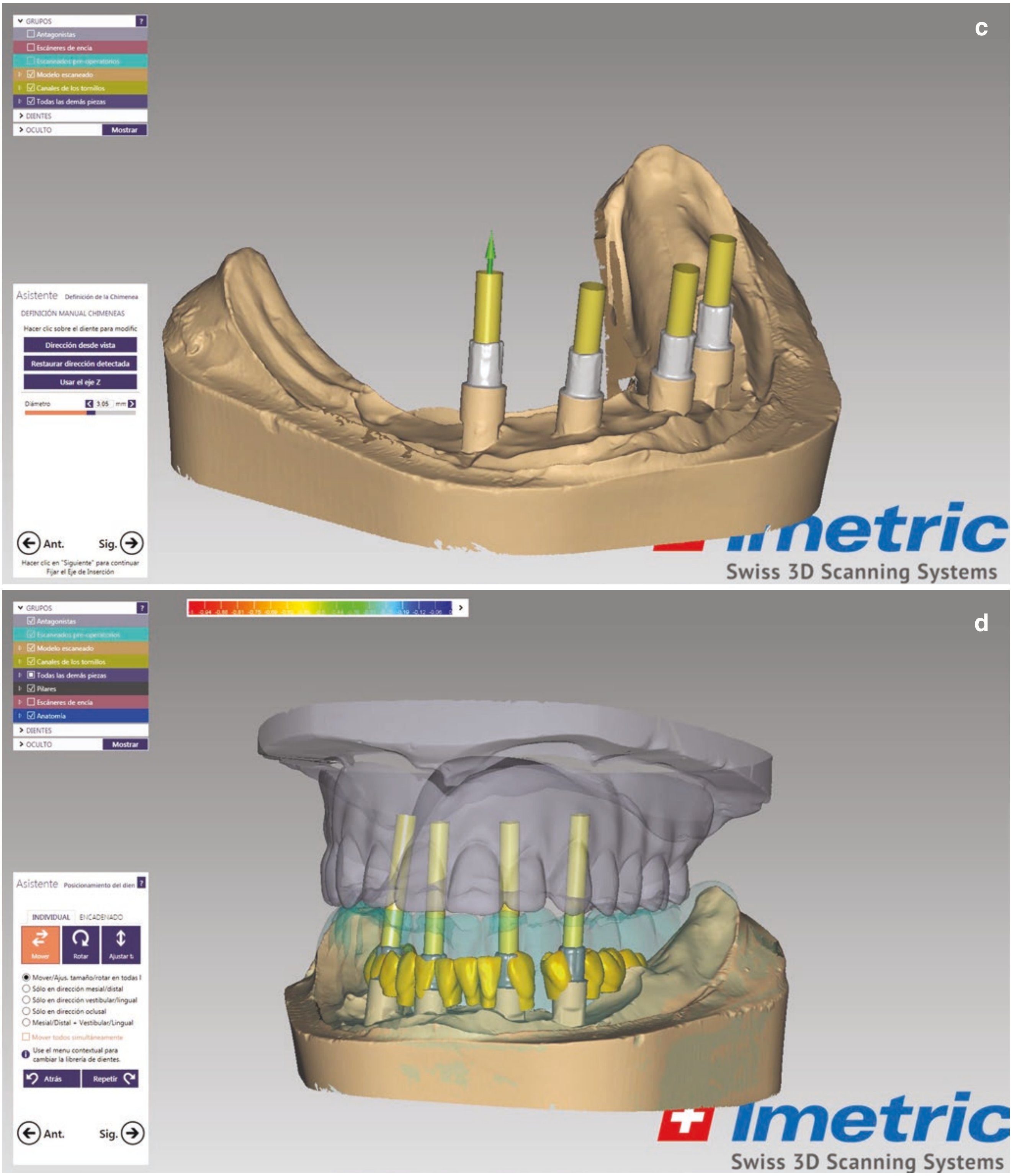


Fig. 108 (**c**) Checking of the parallelism of the emergence profile of the implants. (**d**) Digital positioning of the teeth depending on the antagonist and emergence profile of the implants

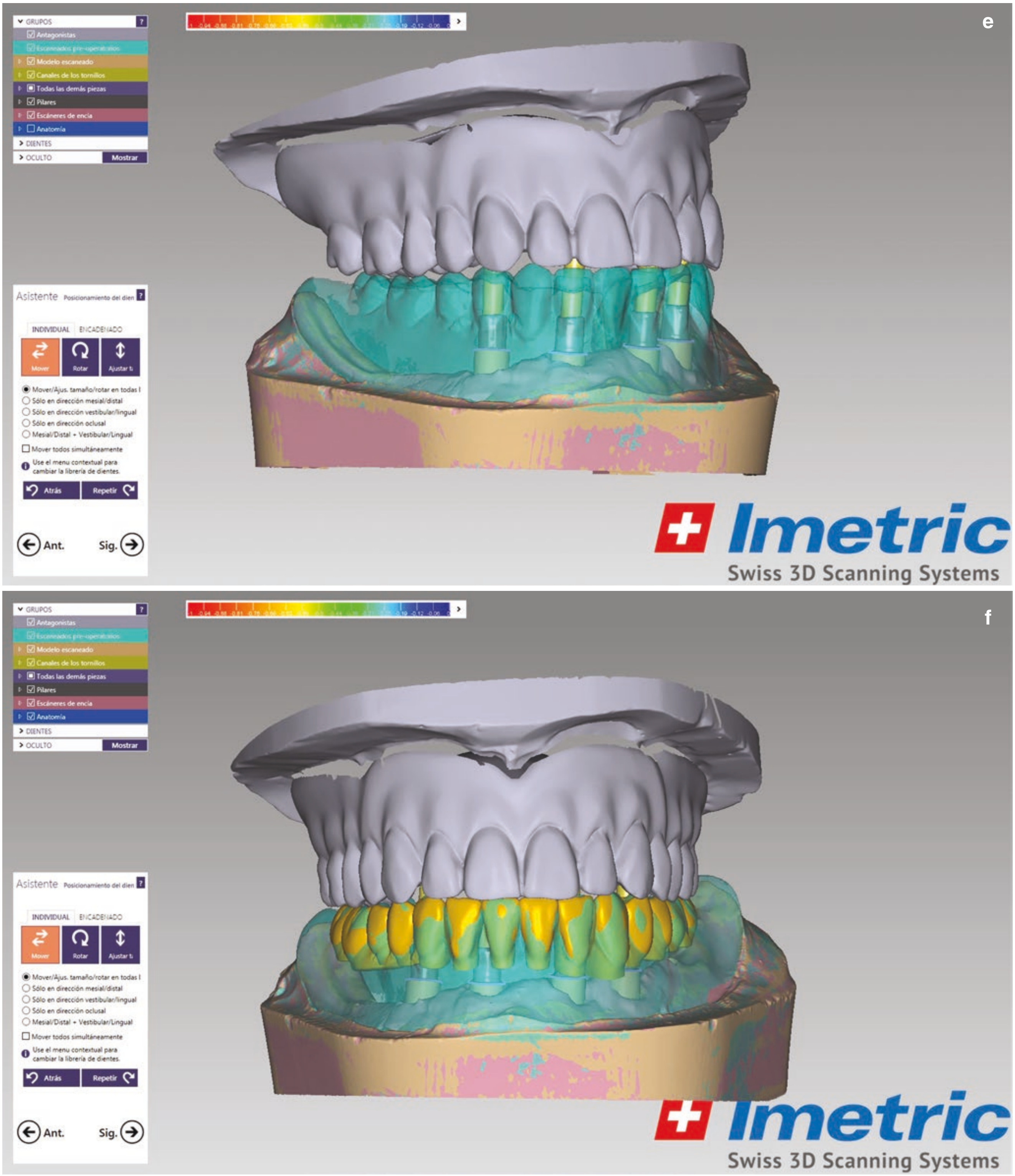


Fig. 108 (**e**) The correct emergence profile of the implants is check in occlusion using the radiographic guide as a model. (**f**) The definitive design of the prosthesis is confirmed in occlusion with the antagonist

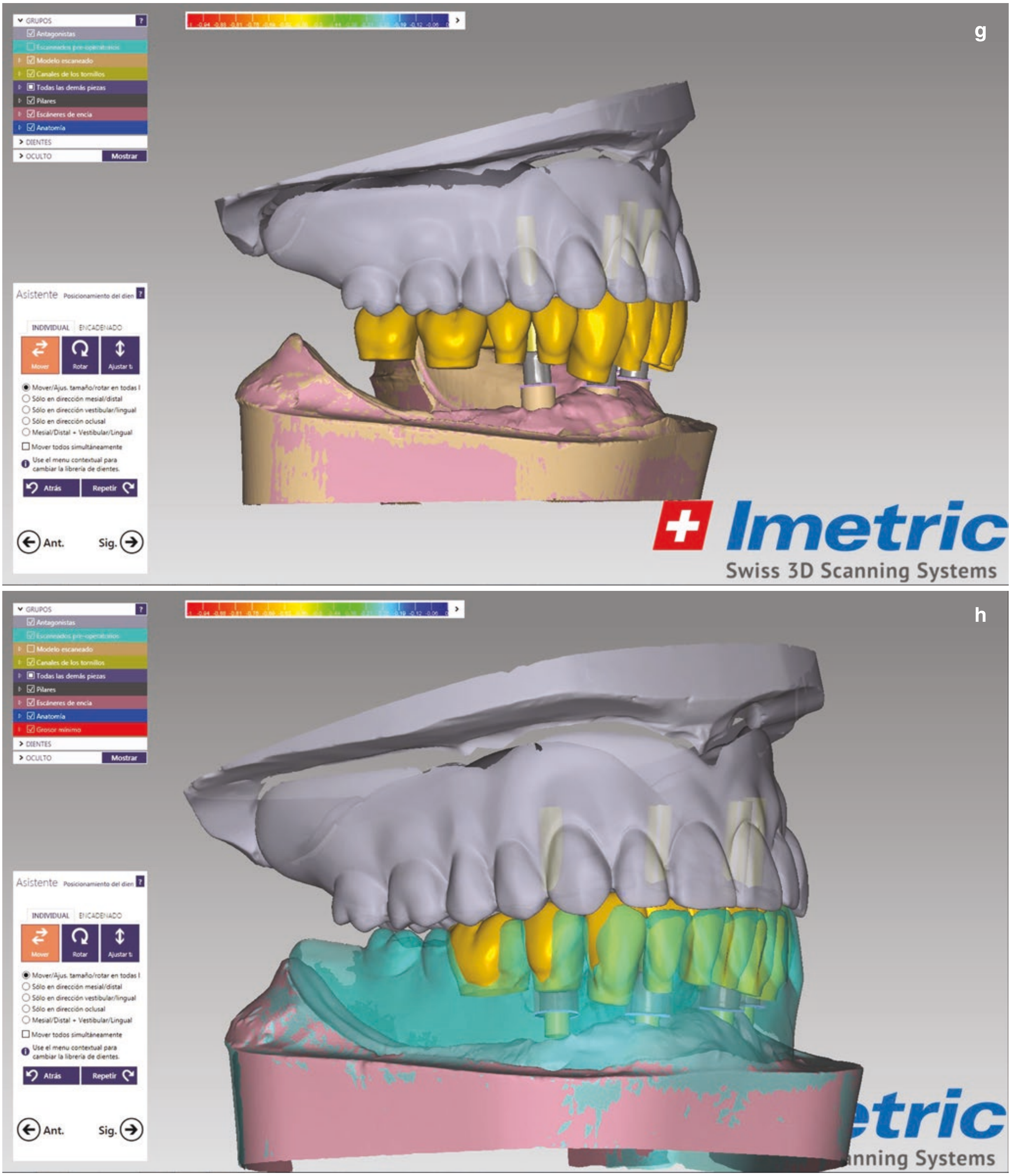


Fig. 108 (**g**) The positioning of the teeth is confirmed laterally. (**h**) The superimposition of the radiographic guide is also done in order to check the design

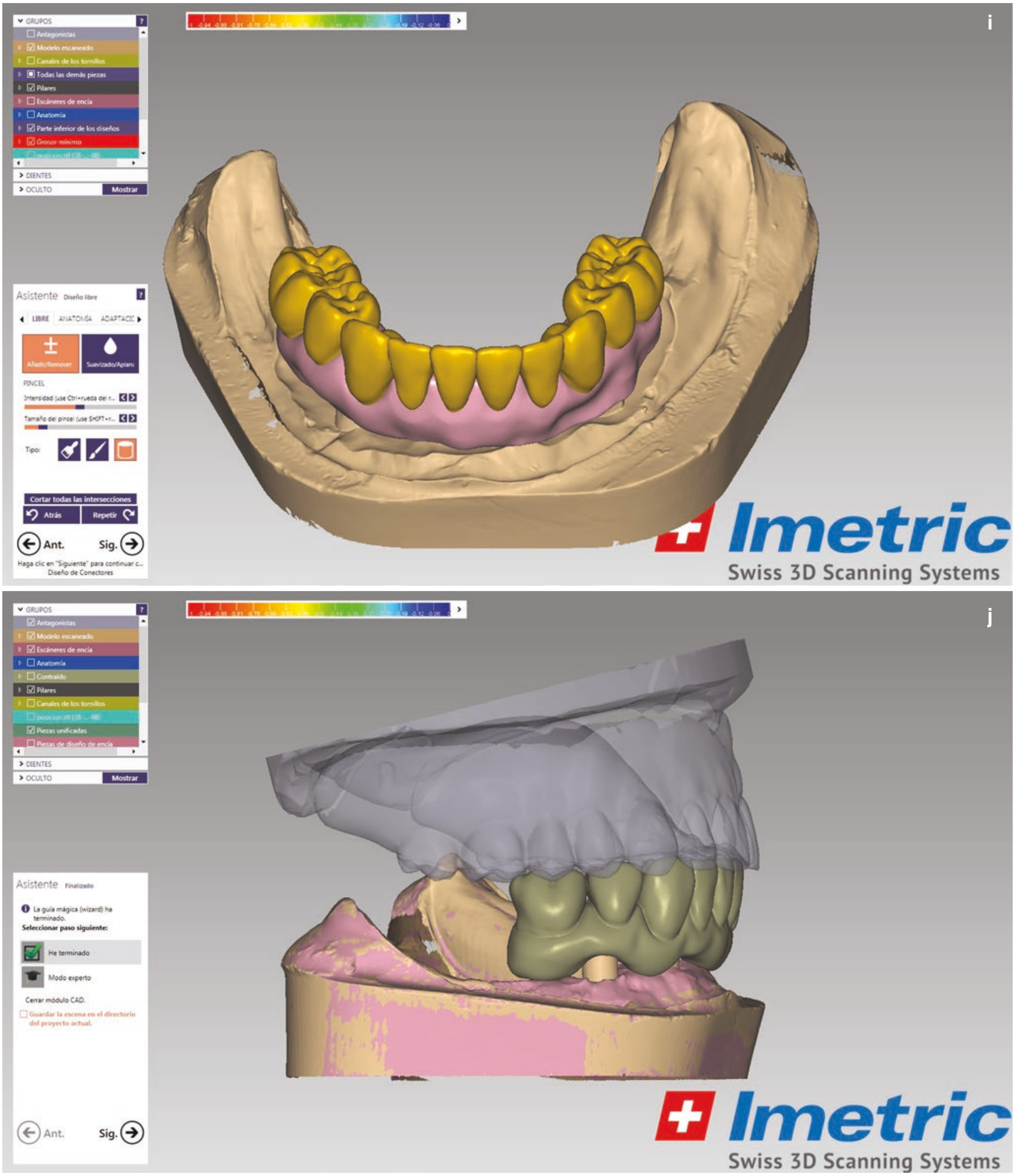


Fig. 108 (**i**) Occlusal image of the definitive design of the prosthesis. (**j**) Lateral image

Fig. 109 PMMA immediate provisional prosthesis

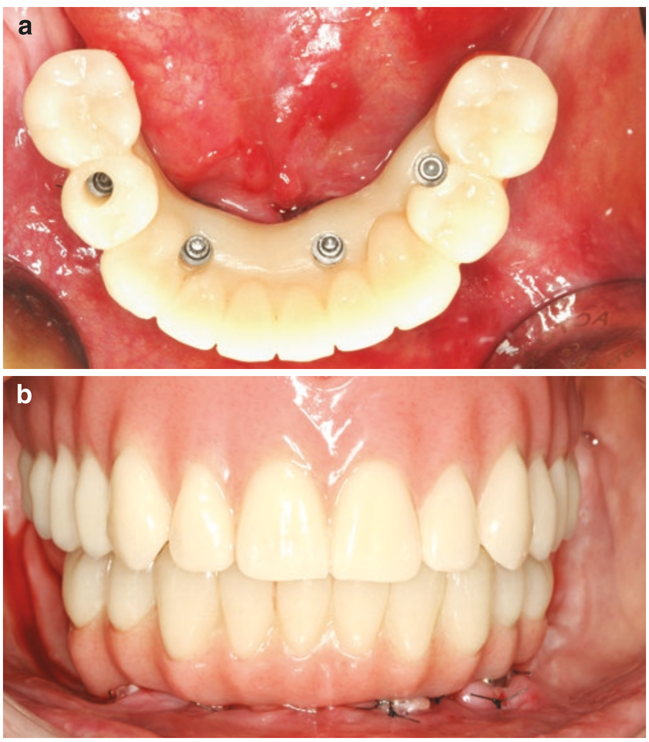


Fig. 110 (**a**, **b**). Prosthesis placed in the mouth

Fig. 111 Profile picture at the moment of the prosthetic load

Prosthetic Procedure

Provisionalization can be done with a prefabricated prosthesis or providing a prosthesis based on a plaster cast made out of a postoperative impression, thereby bypassing the implant deviation between the pre-surgical planning and the postoperative situation related to the inaccuracy of this surgical technique. Delivering a fixed prosthesis based on an impression made at abutment level postoperatively enhanced the proper fit of the prosthesis, but with the guided surgery protocol, the aim is to produce a provisional restoration before the actual surgery, thus allowing, when the surgical condition will permit it, an immediate loading protocol to be applied. Despite the high predictability of 3D planning software, there is always an inaccuracy which can produce the mismatching of the provisional prosthesis. In fact, deviation of the virtual plan of few degrees can prevent a perfect passive fit of the bridge. Albiero et al. (2017) proposed the use of an intraoral welding technique to increase the predictability of immediately loaded implants supporting a fixed full-arch prosthesis after computer-guided flapless implant placement.

So, it is our belief as for Van de Velde et al. (2010), Landázuri-Del Barrio et al. (2013), and Meloni et al. (2013a) that with the current available techniques and reported inaccuracies, it is not possible to prefabricate a rehabilitation completely ready to install on implants, based on the guided treatment planning. To overcome this problem for immediate loading, the passive fit is directly obtained in the oral cavity using resin to connect the temporary cylinder to the metal framework, or it is recommended to take an impression or to use a system allowing the finalization of the prostheses immediately after surgery when following an immediate loading protocol. Nevertheless, Daas et al. (2015) delivered an immediate full-arch rehabilitation over immediate implants with computer-guided implant surgery, and the correct abutment connection was checked visually and assessed radiographically in all the provisional prostheses in their study. If an impression is made, it's important to protect the implants and soft tissue with a rubber dam. D'haese et al. (2013) observed the loss of one implant caused by an abscess related to remnants of impression material.

Complications

The guided implant placement surgery involves a reduction of surgical time, but increased planning time, evaluations, treatment plans, and surgeries have to be performed following established system-specific guided surgery protocols, without alteration. Potential errors, which are additive, can be found in each step in the CT-guided surgery workflow. Manufacturers recommended that implant-specific drilling protocols have to be followed, and attention to detail, understanding the rationale for all steps in the workflow, and avoiding skipping steps are required (Orentlicher et al. 2014).

Moreover, there is a steep learning curve; guided surgery requires greater surgical experience in implant placement and does not represent the first option for young clinician not sufficiently trained in guided implant insertion. Strict adherence to the system protocol is the key to prevent complications.

There are different complications that have been described as complications encountered with the planning procedure using the software system. Early surgical complications have been described as incomplete seating of surgical template or template fracture, limited access; Komiyama et al. (2012) recommend a minimum distance of 50 mm between the residual ridge and the incisal edge of the opposing anterior dentition in order to accommodate the surgical tooling), incomplete implant placement to depth, unstable implant, soft-tissue defects, late surgical complications as prolonged pain and swelling, infection, acute sinusitis, and early and late prosthetic complications including prosthesis and screw loosening, speech problems, biting and fracture of prosthesis frame (Yong and Moy 2008; Di Giacomo et al. 2012).

Different types of errors which could occur during a CT-guided implant surgery and prosthetics are as follows (Bruno et al. 2013):

1. Errors during image acquisition and data processing. It is important to do the calibration of the scan in order to obtain the minor deformation of the surgical template.
2. Error during surgical template production, typically around 0.1–0.2 mm for CAM with stereolithography.
3. Error during template positioning and movement of the template during the drilling.
4. Mechanical error caused by the bur-cylinder gap.
5. In template-assisted surgery, the height of the template necessitates very long burs.

For Abad-Gallegos et al. (2011), after placing 122 implants in 19 patients, the intraoperative surgical complications comprised a lack of primary stability in 26.3% of the implants, thus precluding programmed immediate loading, and technical difficulties caused by limited oral aperture in one patient. The postoperative complications in turn consisted of a lack of implant that led to the failure of seven implants in four subjects. In one case an implant was lost due to infection, and on raising the flap and examining the adjacent implants, important bone dehiscence caused to remove two more. All the implants were posteriorly successfully replaced by an open surgery. Ten cases (52.6%) showed no prosthetic complications. The most frequent complications were screw loosening of the provisional prosthesis (10.5%), fracture of the prosthesis or of some of the prosthetic teeth (10.5%), a lack of passive fit of the immediate prosthesis (5.3%), and implant pain (5.3%).

Di Giacomo et al. (2012) evaluated the accuracy and complications that arise from the use of selective laser sintering surgical guides for flapless dental implant placement and immediate definitive prosthesis installation. Sixty implants and 12 prostheses were installed in 12 patients. The mean lateral deviation was <1.8 mm, and the mean angular deviation was 6.53°. However, 41.67% of the implants had apical deviation >2 mm. The complication rate was 34.4%; this rate pertained to complications such as pulling of the soft tissue from the lingual surface during drilling, insertion of an implant that was wider than planned, implant instability, prolonged pain, midline deviation of the prosthesis, and prosthesis fracture.

Bruno et al. (2013) presented a clinical case of an edentulous woman asked for a lower jaw implant-supported prosthesis; during the surgery two implants were removed because the implants were positioned buccally, and the operator made the decision to continue the surgery free hand and open flap.

Yong and Moy (2008) also reported an implant that was incompletely placed to depth and was removed immediately from total of 78 implants. The authors described the complications, and there were no complications encountered with the planning procedure using the software system. They had early surgical complications (two cases of incomplete seating of the prostheses because of bony interference, one implant incompletely placed to depth), early prosthetic complications (prostheses loosening, speech problems, and bilateral cheek biting), late surgical complications (one patient with resistant pain, one implant with residual buccal soft tissue defect, implant failure), and late prosthetic complications.

As we said, pain and swelling can appear as postoperative complications; Yamada et al. (2015) evaluated prospectively the clinical effectiveness of immediate loading implants with complete-arch fixed prostheses with flapless-guided surgery and found an average score for postoperative pain was 14.7 ± 9.3 in a 100-mm visual analog scale. No surgery-related complications, such as an inability to place the surgical template or insert the drills, fracture of the surgical template, insufficient primary implant stability, or perforation of bone, were observed. Minor bleeding was observed in one patient, but it had stopped by the next morning. With respect to prosthetic complications, screw loosening in the provisional prosthesis was observed in ten implants (six patients) at the follow-up visit. A fracture of the provisional prosthesis was observed in one patient during the healing period.

The most frequently occurring early surgical complications are bony interferences that prevented complete seating of the prosthesis. The surgical procedure is also complicated by poor access in posterior quadrants because of the relatively long drills and thickness of the surgical guide. The poor visibility made it difficult for the surgeon to ensure complete depth of drilling and instrumentation especially in the posterior regions of the partially dentate patients.

All articles written on stereolithographic guides showed deviations between virtual planning and placed implants. The accuracy of guided implant surgery is determined by the sum of possible errors occurring during all steps of the procedure from implant planning over implant installation to prosthodontic reconstruction (Van de Velde et al. 2010). Another factor that can influence accuracy is the type of study (cadaver, clinical, or in vitro).

The deviations between the virtual implant planning and postoperative implant location are important; deviations at the shoulder of the implant are important when a restoration is finalized before surgery. A high accuracy of the guided surgery system, with an average error in the horizontal direction of 1.2 mm and in the vertical direction of 0.5 mm, was reported in a review. Inaccuracies at the level of the implant shoulder result in a misfit of the prostheses and complicate the long-term outcome of the newly installed implants (Van de Velde et al. 2010). Landázuri-Del Barrio et al. (2013) observed a radiographically misfit in 13 of 16 patients; additionally, an extra laboratory procedure was necessary to allow perfect positioning of the prosthesis.

An analysis of the literature on the accuracy of computer-guided surgery yields heterogeneous results (Valente et al. 2009). Jung et al. (2009) performed a systematic review and found studies reporting maximum apical deviation values of 7.1 mm, while others recorded maximum values of only 0.30 mm. In addition, there is no consensus on various aspects: some authors claim more accuracy with tooth-supported templates (Turbush and Turkyilmaz 2012), while others obtain better results with mucosa-supported templates (Valente et al. 2009).

In a recent systematic review, Seo and Juodzbalys (2018) reviewed a total of 119 articles, and 6 of the most relevant articles that were suitable to the criteria were selected. The data included 572 implants and 93 patients. For the authors, mucosa-supported stereolithographic surgical guide showed not exceeding in apically 2.19 mm, in coronally 1.68 mm, and in angular deviation 4.67°.

Different computer-assisted implant placement procedures are currently available. They differ in software, template manufacture, guiding device, stabilization, and fixation. The literature seems to indicate that one has to accept a certain inaccuracy of ±2.0 mm, which seems large initially but is clearly smaller than for nonguided surgery. A reduction of accuracy to below 0.5 mm seems extremely difficult. A common shortcoming identified in the studies included in this review is inconsistency in how clinical data and outcome variables are reported. Another limitation is the small number of comparative clinical studies (Vercruyssen et al. 2014).

Clinical and Radiographic Outcome

They Table 1 represents some of the clinical reports giving detailed information on clinical outcomes with guided surgery.

Type of Edentulism

Most of the published studies are from edentulous patients treated with guided surgery and immediate full-arch screw-retained prostheses. In a recent study published in 2015, Yamada et al. (2015) evaluated prospectively the clinical effectiveness of immediate loading of 278 implants with complete-arch fixed prostheses in 48 patients with edentulous maxillae. Implants were placed with flapless-guided surgery. One year after immediate loading, the implant survival rate was 98.6%. Nevertheless, some studies are from partial edentulism. In an article published by Pozzi et al. (2015), the authors evaluated a minimally invasive treatment of the atrophic posterior maxilla, with axial and tilted implants and immediate loading. In 27 participants with severe atrophy of the posterior maxilla, 81 implants were placed and immediately loaded (axial (39) and tilted (42) implants) with a flapless or miniflap approach. The cumulative implant sur-

Table 1 Clinical reports on outcomes with guided surgery

Authors (Year)	Study	No. of patients	No. of implants	Prostheses	Fully guided implants	Flapless	Follow-up	Prosthesis success (%)	Implants success (%)
Amorfini et al. (2017)	RCT	13	36	Partial fixed	Yes	Yes	2 years	100 (one fracture)	97.3
Ciabattoni et al. (2017)	Prospective	32	285	Full-arch fixed	Yes	Yes	3 years	100	97.54
Vercruyssen et al. (2016)	RCT	7	42	Full-arch screw-retained	Yes	Yes	–	–	100
Sato et al. (2016)	Prospective	–	–	Overdenture	Yes	Yes	–	–	–
Tallarico et al. (2016)	RCT	40	200	Full-arch and all-on-4/all-on-6	Yes	Flapless or miniflap	5 years	100 (two screw loosening and two fractures)	95
Yamada et al. (2015)	prospective	48	278 max	Full-arch fixed	Yes	Yes	12 months	Fracture of provisional prosthesis and screw loosening in ten implants	98.6
Daas et al. (2015)	Prospective	14	99 (max/mand)	Full-arch fixed	Yes	– (soft tissue management in some cases)	Between 6 and 24 months	Three cases with fracture	97.97
Browaeys et al. (2015)	Prospective	20	80 (max/mand)	All-on-4 full-arch screw-retained	Yes	Yes	3 years	100	100 (unacceptable bone loss in 49.2%)
Pozzi et al. (2015)	Retrospective	22	170 max/mand	Screw-retained metal-reinforced acrylic restorations	Yes	Yes or miniflap	Min. of 36 months	88.5	100
Polizzi and Cantoni (2015)	Retrospective	27	106 max (92 healed bones/68 immediate implants)	Full (19) or partial (10) screw-retained	Some immediate implants were placed deeper than planned after surgical guide was removed	Yes	Up to 5 years	100	97.33
Marchack and Moy (2014)	Prospective	1	6 max 5 mand	Full arch screw-retained	Yes	Yes	8 years	100	100
Orentlicher et al. (2014)	Retrospective	–	107	Full-arch and all-on-4/all-on-5/all-on-6	Yes	Yes	7 years	–	97.2 max 100 mand
Galindo and Butura (2014)		1	6 max	Full arch screw-retained	Yes	Yes	18 months	100	100
Meloni et al. (2013a)	Prospective	20	117	Full screw-retained	Yes	Yes or miniflap	30 months	100	97.4
Meloni et al. (2013b)	Prospective	12	72 (26 immediate implants)	Screw-retained	Yes	Yes	24 months	100 (three fractures of the acrylic resin)	100
D'haese et al. (2012)	Prospective	26	114 max	Full or partial screw-retained	Yes	Yes	12 months	11.5% early complications	88.6 survival

Landázuri-Del Barrio et al. (2013)	Prospective	16	64	Screw-retained	Yes	Yes	12 months	100 (misfit 13/16 patients)	90
Kominaya et al. (2009, 2012)	Prospective	29 jaws	165 max/mand	Full-arch fixed	Yes	Yes	12 months	–	98.18
Di Giacomo et al. (2012)		12	60		No	Yes	30 months	91.66	98.33
Abad-Gallegos et al. (2011)	Retrospective	19	122 (max/mand)	Resin bridge/ screw-retained metal-reinforced acrylic restorations	Yes	Yes	–	52.6 (five cases with delayed loading protocol)	69.5
Van de Velde et al. (2010)	Prospective	13	36 max	Partial fixed (cemented or screw retained)	No	Yes	18 months	92.31 (three cases fracture)	97.3
Danza and Carinci (2010)	Retrospective	–	66	Partial and full fixed prostheses	Yes	Yes	15 months	–	100
Meloni et al. (2010)	Retrospective	15	90 max	Full arch screw-retained	Yes	Yes	18 months	Two prostheses not fit and one fracture of the provisional	97.77
Yong and Moy (2008)	Prospective	13	78 max/mand	Partial and full fixed prostheses	Yes	Yes	26.6 months	Two prostheses with heavy occlusal wear and two loosening of the screws	91
Malo et al. (2007)		23	92	Full arch screw-retained	Yes	Yes	1 year	Screw loosening in 15 implants	97.8
Rao and Benzi (2007)	Prospective	46	51	Unitary	No	Yes	1 year	• Five cases of screw loosening • 49% minor adjustments in the cemented restoration	100 (94% for immediate function)

RCT randomized control clinical trial, *max* maxillary, *mand* mandibular vival rate was 96.3% at 3 years. All prosthetic restorations were stable and in good function, resulting in a cumulative prosthetic survival rate of 100%. Despite the statistically significant differences in marginal bone between axial and titled implants, there was no clinical significance. The authors concluded that treatment of the posterior partially edentulous atrophic maxilla with guided surgery and immediate loading of tilted and straight implants supporting short-span partial fixed dental prostheses was effective. In 2010, Van de Velde et al. (2010) compare the outcome of dental implants placed using a flapless protocol and immediate loading with a conventional protocol and loading after 6 weeks. In 13 patients with 36 implants placed in the posterior maxilla using a stereolithographic surgical guide for flapless surgery and immediately loaded on temporary abutments with a bridge, the authors found a survival rate of 97.3%. Fractures of the provisional prostheses were seen in three cases.

D'haese et al. (2013) compared in a prospective study the outcome of implants placed using stereolithography-guided surgery in 26 cases with a partially or totally edentulous maxilla with 114 implants. In total, 38.5% of the subjects with a full immediately loaded fixed dental prosthesis experienced implant failures compared with 15.4% of the partially delayed loaded cases at 1-year follow-up.

Type of Bone

As we said before, in most studies implants are placed in healed bone. Nevertheless, when the impacts are placed in postextractive sockets, implant insertion is usually planned along the palatal socket wall and 1.5 mm below the coronal vestibular alveolar crest (Tallarico et al. 2016). Meloni et al. (2013b) published a study using computer-assisted implant surgery and immediate loading where 72 implants were placed and immediately loaded (26 of which were inserted in fresh extraction sockets). The cumulative survival rate was 100% after 24 months of follow-up. Polizzi and Cantoni (2015) evaluate midterm follow-up of patients with compromised dentition treated with immediate fixed restorations on maxillary implants inserted in fresh extraction and healed sites in combination with a specially designed radiographic stent. Twenty-seven patients were treated with immediate full-arch or partial restorations with 160 implants founding a 97.33 cumulative survival rate with a 5-year follow-up. Bone loss from insertion to 2 years, for implants placed in both extraction and healed sites, was 0.85 mm; from insertion to last radiological control (4–5 years), 1.39 mm; and between 2 years and last control, 0.64 mm. No bone loss difference was found between extraction and healed sites.

Ciabattoni et al. (2017) published a 3-year clinical and radiological study of 32 patients that were treated with immediate full-arch restorations and flapless implant surgery in fresh extraction and healed sites. A double-guided technique stent was used and a total of 285 implants were placed. One hundred and ninety-seven implants were placed in extraction sites (137 maxillas, 60 mandibles) and 88 in healed sites (58 maxillas and 30 mandibles). The overall cumulative implant survival rate (CISR) was 97.54%. Two implants failed in maxillary healed sites (CISR 96.55%), three in maxillary extraction sites (CISR 97.81%), and two in mandibular extraction sites (CISR 96.66%). No implant failed in healed mandibular sites (CSR 100%). So, the authors concluded that computer-guided surgery using double-template technique (DTT) shows a predictable outcome in the medium term, decreasing treatment timing and patient discomfort.

Marginal Bone Loss

Although positive results have been presented in several reports using immediately loaded implants using computer-guided treatment planning and flapless surgery, the reported scientific data have focused mainly on the survival/success of the inserted implants and fixed dental prosthesis. Only a few studies have evaluated the clinical condition of the supporting peri-implant tissues, including marginal bone loss. Komiyama et al. (2012) evaluated 29 edentate jaws treated with 165 implants, peri-implant soft tissue conditions, and radiographic marginal bone changes. Bleeding on probing was recorded as a mean of 81.9%. A marginal bone loss more than 1.5 mm or 2.0 mm was observed in 42% and 27% of the measured sites, respectively. Although the mean marginal bone loss after function was within the range of other reports, patients showed a wide range of bone loss with several sites, where the bone loss was greater than the commonly used successful level (>1.5 mm).

Landázuri-Del Barrio et al. (2013) in a prospective study on 64 implants installed with a flapless-guided surgery using the all-on-four concept in the mandible in 16 patients found a survival rate of 90%. The mean bone level after 12 months was 0.83 mm with a maximum of 1.07 mm. A stable soft tissue condition was seen as 83% of the implants showed shallow pockets and no significant midfacial recession. Plaque (<27%) and bleeding (<30%) remained fairly low which coincided with limited bones loss (<1 mm).

In our opinion, further prospective studies and more randomized clinical trial with medium- to long-term follow-up are needed in order to find the best guiding system or the most important parameters for optimal accuracy. Information on cost-effectiveness and patient-centered evaluations (i.e., questionnaires and interviews) must also be included.

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The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: The Basics

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Take Home Message
The introduction of the technology in dentistry has created the need of establishing new workflows that are required to be reproducible, quick, and easy. This digital dentistry implies the acquisition of new knowledge and tools that will ensure the success of our treatments, involving not only new physical elements (intraoral scanner, Osstell, etc.) but also a few strict protocols that are going to guarantee the best results of our daily practice.

Introduction

Technology has become part of our lives, to the point that it now constitutes an essential element of our own development. It enables us to do new things and moreover allows the things we have always done to be carried out better and faster. It is a fact that the current standards of living and well-being could not be upheld without our technological advances. Implantology is no exception to this situation, and over the coming years, the technological dimension of the processes inherent to this discipline will undoubtedly grow far more.

The incorporation of new techniques and processes in the health sciences should occur once they have been shown to be superior to the classical procedures, affording fundamental advantages for the treatment of our patients. Odontology has experienced great development in recent years. Such development is largely attributable to the introduction of potent designing software and modern fabrication systems that offer surprising outcomes from both the esthetic and the functional perspective and all with minimization of the time requirements—thus allowing patients to recover chewing function and esthetics in a short period of time.

The introduction of the intraoral scanner in implantology has been a technological revolution in intraoral digital impressions, which are now able to replace conventional impressions. However, this is no mere switch from one process to another that offers more advantages. Indeed, the intraoral scanner opens up new perspectives in implant treatment thanks to its increased accuracy and speed and offers new digital design and production possibilities resulting in precision and quality standards never seen before in implantology. In our opinion, it is very important not to try to reproduce the same classical processes in this new digital world but to develop new processes based on digitalization and which are superior to the old protocols. Doing so will allow us to offer our patients the best possible treatment in this first quarter of the twenty-first century.

The intraoral scanner allows us to obtain a precise recording of the surface and morphology of the oral cavity. It is able to record the gums, teeth, implant abutments, restorations, mucosa, and tongue. As operators of the system, we modulate these recordings to make the data they contain applicable and useful. The obtainment of digital intraoral impressions is associated with less patient discomfort and is faster and more precise than the obtainment of impressions using the classical procedures. With only minimal training, the intraoral scanner system stops being operator dependent and becomes more plastic. Furthermore, it allows better communication with the patient and with the working team—including the dental laboratory staff (Fig. 1).

The intraoral scanner also allows extremely precise implant planning thanks to new software tools. The aim of such software is to design and produce not only the surgical guide but also a provisional prosthesis to be placed after guided dental implant placement. Quite fittingly, these tools are referred to as guided prostheses software.

This new technology can likewise be used to obtain impressions of the implants and perform immediate loading from the individual crown until full arch rehabilitation. Many of these prostheses can be developed at the patient chairside.

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Fig. 1 Different IOS: caption unit, computer with software

In addition, we can compare the evolution of the reconstruction techniques and communicate better with the patient and with the other professionals involved in patient care, adopting a digitally guided, integral multi-specialist approach.

From the patient's perspective, intraoral scans are more comfortable than impressions. Several studies within the literature report patient preference for impressions taken using the intraoral scanner in terms of comfort and perceived accuracy relative to conventional impressions (Yuzbasioglu et al. 2014a; Gjelvold et al. 2016; Ender and Mehl 2013a; Müller et al. 2016). It can also significantly reduce both chair time and number of needed appointments to achieve the final result. As a result of the increasingly greater accuracy of the intraoral surface scanners, these systems are gradually replacing the classical procedures for obtaining impressions.

"Full digital" means a complete workflow starting by the collection of 3D images through the intraoral scanner and following multiple steps that lead us to the final result in a CAD-CAM environment. This digital workflow will offer to the dentists, lab technicians, and patients high-quality results and treatments in terms of accuracy, precision, quickness, etc. (Yuzbasioglu et al. 2014a; Gjelvold et al. 2016; Hack and Patzelt 2015).

The obtaining of impressions is much faster than with the conventional methods. Improved communication with the patient—with visualization of the scan on the screen—and with the dental laboratory, allowing instantaneous file transmission and the possibility of remote interaction with the clinic, results in a radical change in dental care, much better adapted to both the patient and the working team. It is of maximum importance to develop specific operating protocols to guarantee the best results in a clear and reproducible way. Moreover, thanks to these techniques, the risk of errors and imprecisions associated with the more artisanal or manual techniques is greatly reduced. Accuracy and precision are notoriously improved as a result.

Errors can occur with any recording system. Logically, intraoral scanning systems do not pose the same dimensional stability and accuracy problems as those associated with the materials commonly used in obtaining conventional impressions (Anh et al. 2016; Nedelcu et al. 2018). Nevertheless, with the IOS there are situations—particularly in implantology—where recording errors can occur, and we must know these situations in order to adopt preventive measures.

Our concept is not to fully replace the classical workflow with the digital workflow; rather, the aim is to allow both approaches to coexist and combine to the benefit of our clinical outcomes and our patients. Perhaps the most important reflection regarding the digital process in the dental clinic is that these novel operating protocols should not be a mere transfer of the classical processes to the digital world. We need to develop new and different protocols with a view to drawing advantages from this technology.

However, it is important to take in count that these protocols are according to our experience and the current state of the technology, as this may well change in the near future.

Immediate Loading

The purpose of treatment with immediate fixed prostheses over implants is to offer the patient a fixed prosthesis from the day of dental implant placement, in order to improve patients' quality of life, maintaining the prosthesis during the months needed for osseointegration to develop and consolidate. The full digital protocol makes this process more precise, rapid, and predictable, and of greater quality, and moreover generates a treatment workflow destined to secure an absolutely correct definitive prosthesis (Figs. 2 and 3).

A common situation found in digital immediate provisionalization is that in some cases where multiple implants are placed, even if all the implants fulfill the immediate loading parameters, we can decide to load only some of the placed implants, whether guided or not. It is not necessary to load all the implants in this first phase—only those that are required for supporting the provisional prosthesis with the required guarantees. In some situations, at later stage,

Fig. 2 Preoperative appearance of a patient

Fig. 3 Same patient after a full digital full arch immediate loading and final prostheses

we could place additional implants in areas which, i.e., we have allowed to heal or have regenerated, while the patient continues to carry the same fixed provisional prosthesis.

In this chapter we will discuss all the elements involved in our protocol for full digital same-day immediate loading. Please be aware that this treatment concept is comprised by the proper use and application of all these elements and different recommended protocols using these elements, to be applied in the different clinical situations presented in a full edentulous patient.

Elements Implicated in Treatment

1. Intraoral scanner
2. Adequate implant
3. Surgery
4. Osstell
5. Laboratory design software
6. Production machinery and software
7. Provisional prosthesis (Fig. 4)

In relation to these elements, the protocol includes a modified surgery, an implant stability quotient measurement (ISQ), a proper scanning workflow, a convenient design of the provisional prosthesis, and its final production in PMMA.

Fig. 4 Elements and treatment tools

The detailed analysis of each of these elements and workflows exceeds the scope of this chapter. We therefore will focus on their description from an exclusively practical and clinical perspective.

Intraoral Scanner

In our practice we use the TRIOS 3 scanner from 3shape. This system is sufficiently precise to allow totally reliable utilization in any application involving the obtainment of digital intraoral impressions (Nedelcu et al. 2018; Basaki et al. 2017) (Fig. 5).

This covers implantology, in all its applications, from single to full arch implant procedures, orthodontics, prostheses over natural teeth, etc. The intraoral scanner records data from the oral cavity of the patient and generates a file that in turn can be processed using prosthesis design software.

The current intraoral scanners offer greater accuracy than the conventional materials (Hack and Patzelt 2015; Anh et al. 2016; Basaki et al. 2017; Sahin and Cehreli 2001; Marghalani et al. 2018). The literature confirms that when impressions are obtained with conventional materials (silicones and polyethers), and a conventional working cast is generated, the sum of different factors such as the impression technique, operator skill, the position, number and angulation of the implants, the impression material used, casting, patient tolerance of impression, the dental laboratory, and the physicochemical properties of the materials all contribute to generate inaccuracies of close to 50–70 μm (Hack and Patzelt 2015; Kim et al. 2017; Amin et al. 2017; Papaspyridakos et al. 2015; Andriessen et al. 2014a). According to the available literature, intraoral scanners offer accuracy and consistency performances of up to 6.9 ± 0.9 μm and 4.5 ± 0.9 μm, respectively (Hack and Patzelt 2015).

There is a lack of consensus regarding how accurate a digital impression must be, to be clinically useful. For implant impression scanning, in vitro analysis has presented an error of less than 60 μm as clinically acceptable (Basaki et al. 2017). This is based on an older review discussing the need for accu-

Fig. 5 TRIOS 3 from 3shape

racy of implant position to obtain a passive ("perfect") framework fit for an implant-supported prosthesis. The authors' reasoning for this choice of limit is that it is the minimum error detectable in a clinical setting (Sahin and Cehreli 2001).

For implant impression scanning accuracy, none of these studies report a poorer accuracy than the 60 μm mentioned (Basaki et al. 2017). Please note that only very recent studies (predominantly from the last 2 years) have been included, as the technology changes and improves at a fast pace (Gherlone et al. 2016; Lo Russo and Salamino 2017a; Lo Russo and Salamino 2017b; Goodacre and Goodacre 2018).

Therefore, we should establish protocols that are able to reflect such accuracy in our treatments.

Digital scanning of highly edentulous patients presents different challenges compared with fully dentate patients and partial edentulous. Intraoral scanners take many consecutive images and then stitch them together to form the 3D file. This requires easily identifiable landmarks that are placed in an irregular/asymmetric pattern. Highly edentulous patients often have either very smooth gingiva with few landmarks or have very mobile soft tissue (especially in the mandible) that can move during scanning. Both these issues complicate the image stitching leading to an inaccurate file (Seelbach et al. 2013; Papaspyridakos et al. 2014; Yuzbasioglu et al. 2014b; Andriessen et al. 2014b).

Therefore, when scanning, the main problem is the existence of zones with insufficient geometrical information and/or mobile areas. We therefore need to adequately plan the case in order to avoid as far as possible those zones with unclear or erroneous information, corresponding or not to the edentulous zones. A protocol seeking to prevent the elimination of these geometrically significant structures (which will allow faster and more precise scanning) until after scanning has been completed will place us in the best position for obtaining a highly accurate data file.

A greater presence of these geometrically significant and different structures in the mouth and subsequently in our scan file will result in faster and more precise scanning, with the consequent conformation of a valid scan volume (Ender and Mehl 2013b, 2015; Lee 2017; Fang et al. 2017).

As an example, in the case of the failing dentition of patient to be immediately restored with implants, one possible strategy in this respect is to perform tooth extraction after intraoral scanning, not before. The case should be planned seeking to obtain the maximum information about the oral situation, avoiding the problems created when we modify the patient situation. More than ever, we need to be clever in planning our case. We must think differently, creating new specific workflows for digital dental practice.

Furthermore, in order to draw the maximum advantage from the software, we always must try to obtain a comprehensive main scan volume in a single sweep, without stopping, containing all the significant elements of our treatment. Subsequent accessory scans can be performed to complete the main volume scan. In the case of difficult or non-valid partial scans, it is advisable to even totally erase the file and start over again, until a satisfactory main volume scan is obtained.

A series of accessories called scan bodies are affixed to the implants or abutments to obtain the digital information regarding the position of the implants in the jaw. The scan body replaces the conventional coping in the obtainment of impressions. This accessory possesses a geometrically significant zone that is used to perform the digital cast (best fit/alignment) with the laboratory software. Using an intraoral scanner, we have the enormous advantage that the software only needs us to have recorded this geometrically significant part (joined to the main volume scan file) in our scan in order to obtain the position of the implants. In other words, it is not necessary to record the entire scan body to do our work. The laboratory software performs a comparison—manual or automatic—of the two files: that corresponding to the intraoral scan versus that of the digital replica (library) of the scan body. By marking one to three points in the same position in both of them, the software uses alignment algorithms to position the implants and allow us to start designing (Figs. 6, 7, and 8).

This comparison and alignment tool of the CAD design software is essential for our different protocols, since it

Fig. 6 A main volume scan in a case with implants (scan bodies) and natural tooth

allows us to align and overlap files of the same patient, each containing different information but with same structures present on the different files, in different treatment steps, to generate a working file containing all the information required to work with the maximum precision and convenience.

It is important to underscore here that the scan body is the key to design in the laboratory. Each scan body is related to its own digital library, and we use it to design the prosthesis. Accordingly, and although there are exceptions, for a given scan body, we can only use the accessories and design elements contained in its library. In many cases this will mean that the production is either in-house (open), using an independent milling machine or printer, in a clinic or laboratory, or that it inevitably must be carried out in an external milling center.

Fig. 7 Same case different view

We therefore always need to previously decide what type of prosthesis we will produce, what prosthetic accessories we will use, and where the work will be carried out (produced), before selecting the scan body and starting to scan.

Scanning Workflow

When performing an intraoral scan to design and produce a dental prosthesis, the intraoral surface scan is used to transfer the position in the space of the scan bodies and therefore of the implants, including the orientation of the implant prosthetic connection, the soft tissue morphology, inter-arch relationship, and occlusion of the patient. Our aim in all cases is to transfer the precise geometrical and functional information needed by the design and production software, to produce a precise prosthesis.

The usual workflow involves scanning the jaw being treated, the antagonist, and patient occlusion. In the case of implant treatments, a scan body connected to the implant is used to position the implant. Scanning therefore will include the graphic image of that scan body. Optionally, we can include a previous scan—the emergence profile of the implants—before connecting and scanning the scan body. The correct scanning workflow option is conditioned to the clinical case involved.

In certain cases, and to help the dental technician with the design, we can add an additional file: that corresponding to

Fig. 8 Different scan bodies

the pre-preparation scan, which, for example, reflects the maxillary morphology before the extractions or an esthetic mock-up of the case.

Correct scanning for immediate loading will include the following:

1. Scanning of the antagonist arch
2. Optional pre-preparation scan
3. Optional emergence profile scan
4. Scan of the scan bodies
5. Scan of occlusion

Correct use of the intraoral scanner is essential in order to obtain a correct file. Furthermore, it is crucial to scan correctly, and although it may seem obvious, we need to be able to identify when the digital impression is incorrect. There is no single best way to scan: it is largely dependent upon the operator. Our modification in this respect is to perform the initial scan not perpendicular to the occlusal surfaces but at an angle of about 30 degrees from the internal surface, either lingual or palatine, followed by completion of the entire scan. In the case in single implants, the pre-preparation scan is usually not necessary, and scanning of the emergence profile is very important in esthetically important zones. Here again, however, the situation differs from one clinical case to another. During scanning, continuously inspect for stitching errors. If observed, stop scanning, trim the affected area, and re-scan (Figs. 9, 10, and 11).

Many researchers have speculated that scanning accuracy might be improved by adding markers to the edentulous ridge or the palatal area. The underlying concept is that non-symmetrical landmarks aid in the image stitching process for the intraoral scanner. However, the results are ambiguous; for example, some authors reported no accuracy effect of markers. In a test of different marker types and positions on the palate of a completely edentulous patient demonstrated that a marker placed in the middle of an edentulous gap (three missing teeth) affected accuracy but to a varying degree, depending on intraoral scanner tested (Kim et al. 2017). In our clinical experience, it is not necessary to place any additional marker, if the operator has enough experience and a careful scanning workflow has been used.

Adequate Implant

We must choose an implant that could be placed with a simple and plastic surgical protocol, allowing us to, i.e., adapt the surgery to the characteristics of the receptor bone (Fig. 12).

Ensuring high and cautious implant insertion torque when surgical preparation of the bed is correctly performed is mandatory. Self-threading root-shaped implants, as well as implants with broad threads, are ideal for this application (Dard et al. 2016).

It is also important to use treated surface implants. Thanks to their micro-surface characteristics, optimum implants allow improved peri-implant bone response and higher extraction torque values compared with conventional implants (Gottlow et al. 2008, 2010) and can be satisfactorily used in immediate treatment protocols (Buser et al. 2013a, b; Nicolau et al. 2016).

Furthermore, it is important to consider the following:

1. The design of the prosthetic interface (connection). The design should exhibit an adequate conicity in order to

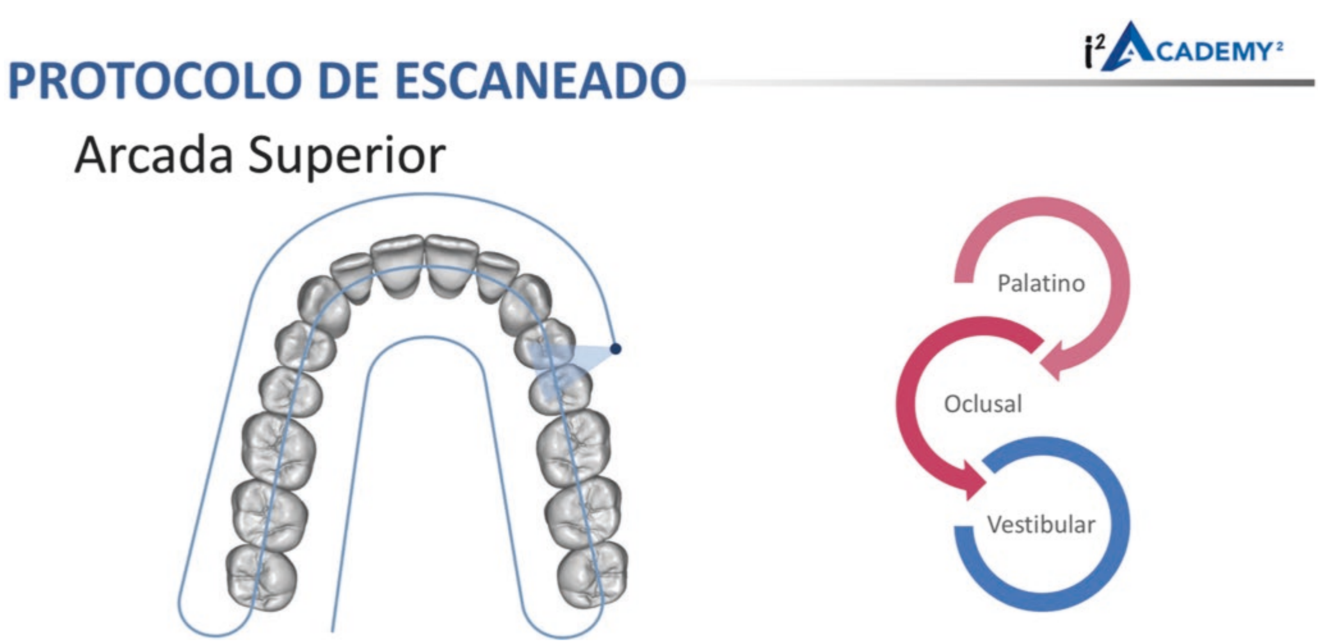

Fig. 9 Upper maxilla scan path

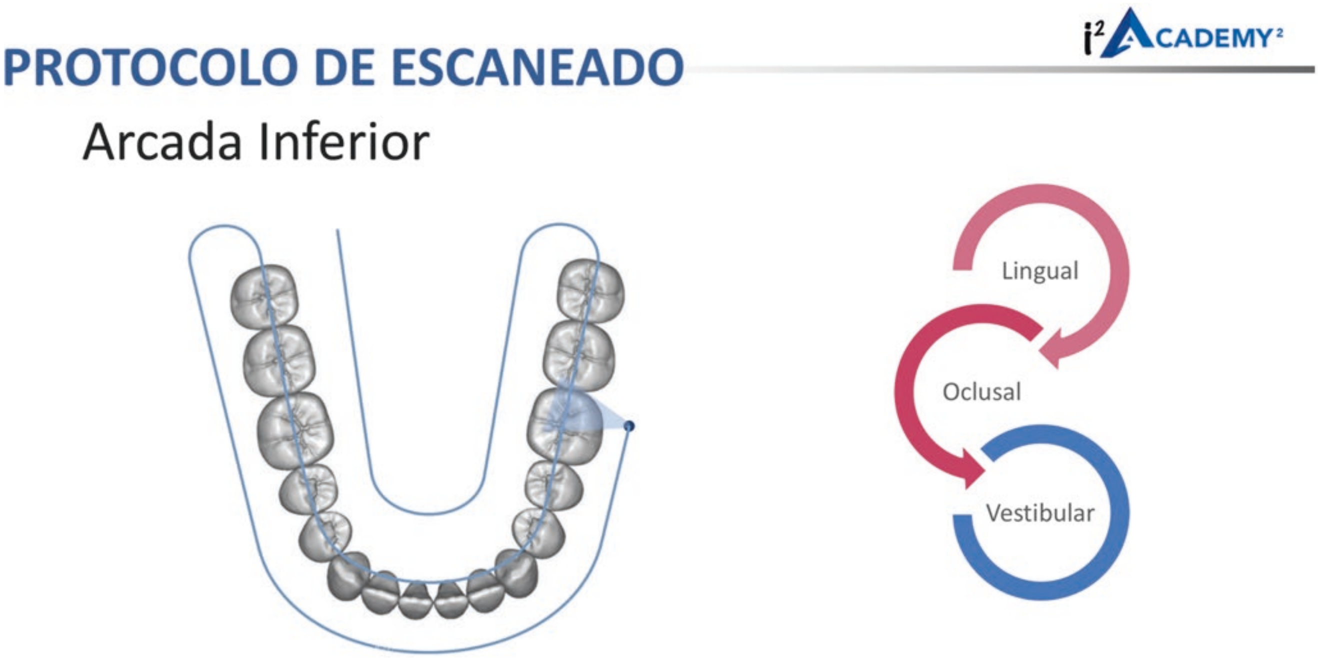

Fig. 10 Lower maxilla scan path

Fig. 11 Occlusion scan path

facilitate fitting of the prosthesis directly onto the implant when using titanium bases in multiple implant treatment with bridges or full arches, direct to the implant. Even with the best IO impression, extreme conicity will mean that the prosthesis cannot be fitted if there is disparallelism between the implants superior to the implant connection angle. This moreover refers to only two implants; the situation worsens even further as the number of disparallel implants intended to house the structure increases.

2. In totally edentulous patients it is advisable to place an intermediate abutment and scan to abutment level by means of the adequate scan body.
3. The production possibilities of the temporary prostheses, with a view to freely deciding whether to produce on an in-house basis, in the clinic or laboratory, or outsourcing, sending the file to an external milling center. It is therefore very important to clearly know the entire treatment workflow, including what scan body we must use to produce under the conditions the working team desires (Figs. 13 and 14).

Fig. 12 Some implants adequate for immediate loading

Fig. 13 Some ti-bases and abutments

Surgery

We must adapt our surgical technique to minimize the problems that may arise when performing immediate loading with an intraoral scanner. The following recommendations can be made in this respect:

1. Minimally invasive surgery. If possible, without flap elevation. The greatest problem facing the intraoral scanner is mobile tissue. Since such tissue is in continuous motion, the scanner is unable to register it correctly. The possibility of soft tissue mobility therefore must be reduced (Figs. 15 and 16).
2. Sometimes, when using flaps, before scanning, fixation suturing of the flaps to the underlying bone is performed, in order to minimize flap movements. Strategic orifices are made in the bone for this purpose, allowing simple suture anchoring of the flap. This strategy not only prevents flap movements but also contributes to improve the clinical course, with less patient discomfort and inflammation (Figs. 17, 18, 19, and 20).
3. During surgery it is very important to take bone density into account and to adapt the diameter of the preparation in order to ensure adequate implant insertion torque and stability.
4. Careful and minimally invasive surgery will allow us to avoid soft tissue damage.

Fig. 14 Some implant connections

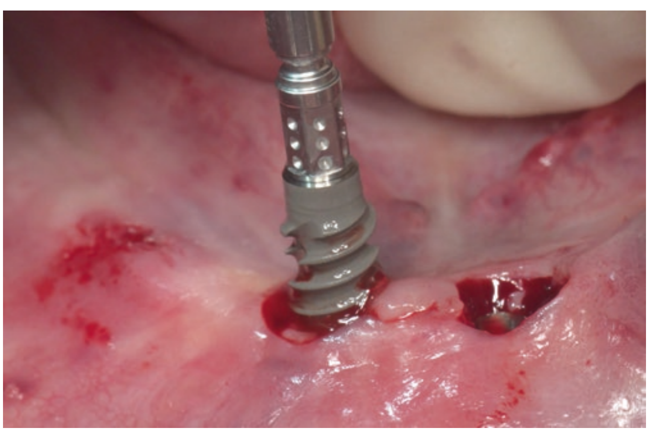

Fig. 15 Flapless implant placement

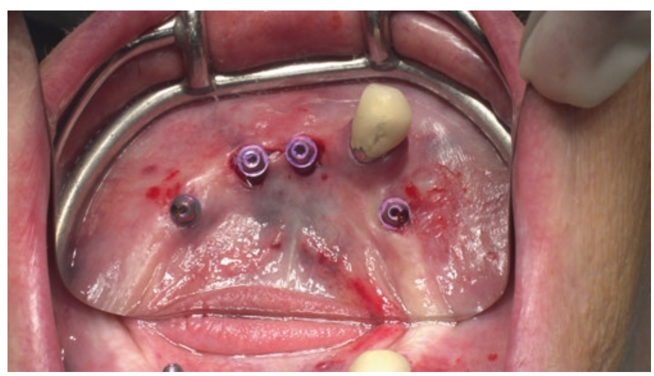

Fig. 16 Flapless surgery

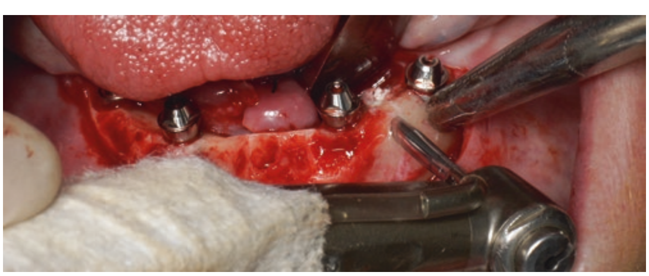

Fig. 17 Fixation suture. Performing the bone holes

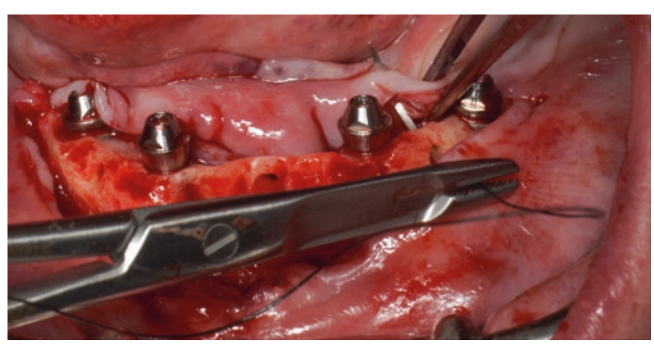

Fig. 18 Fixation suture. Stitching

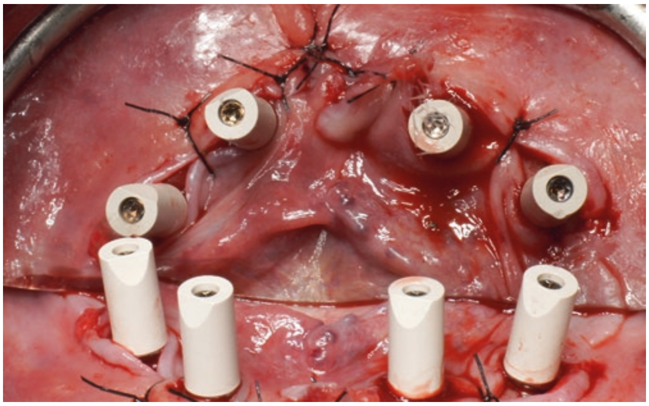

Fig. 19 Fixation suture. Floor of the mouth firmly attached to the bone. Scan bodies in place ready to be scanned

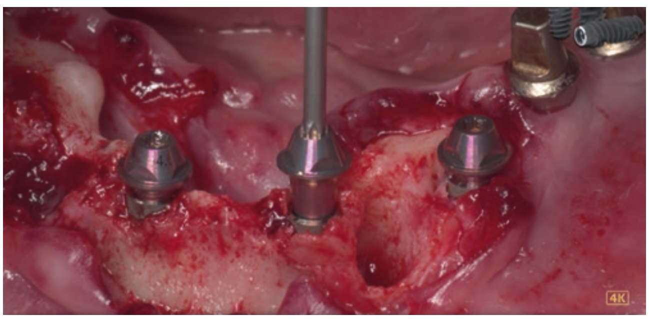

Fig. 20 Abutment connection

5. Use of grafts. In post-extraction cases, particularly single extractions and involving esthetically sensitive zones, we always fill the gap, regardless of its size. In this regard, the use of connective tissue grafts or heterologous soft tissue augmentation material will depend on each individual case. In our experience, the combination of immediate provisionalization and filling of the gap with autogenous bone and biomaterial in most cases suffices to secure long-term stability of the esthetic labial margin (Beom-Park et al. 2006; Shin et al. 2014).
6. Ensure minimum disparallelism between implants, in order to avoid problems with rehabilitation. The combination of guided implant drilling or placement after exhaustive guided planning and final intraoral scanning of the implants is undoubtedly a safe strategy for securing the best outcomes.
7. Careful hemostasis.

ISQ Reading

The possibility of monitoring the immediate loading capacity of the implant by determining *with Osstell* the implant stability quotient (ISQ) is very important, since it is the only objective parameter available and which can be evaluated over time. After surgery, we can follow up on the evolution of the ISQ when there are no further explorations that can help us and which can be contrasted in time.

An ISQ of over 65 would be indicative of the possibility of immediate loading. Nevertheless, when deciding to perform immediate loading, we also must remember to assess other general patient factors (e.g., diabetes), local factors (malocclusion), personal surgeon impression at surgery, insertion torque, number of implants destined to support the load, and alternatives to immediate loading. Only after a detailed analysis of all these elements can we feel sure of making the right clinical choice. We consider it essential to record the ISQ even for medical-legal reasons.

We always record the ISQ at implant level, and in those cases where a transepithelial abutment is placed, the ISQ must again be recorded at abutment level. By extrapolating the implant value to the abutment value, we can get an idea for future ISQ monitoring without having to disassemble the abutment to again record the value at implant level (Nakashima et al. 2018; Sciasci et al. 2018; Lages et al. 2017) (Figs. 21, 22, and 23).

Fig. 21 Osstell

Fig. 22 Implant motor with integrated Osstell

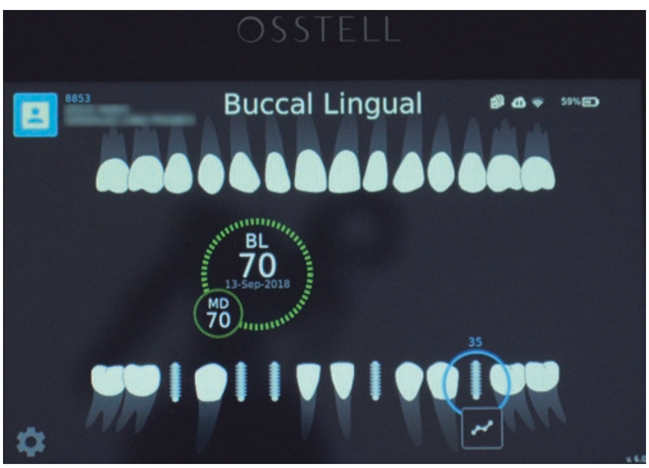

Fig. 23 Osstell screen

Laboratory Design Software

Using the correct library, the laboratory design software should allow us to design the prosthesis based on the pre-preparation, aligning the different files by matching zones or points, as will be explained later, in our different protocols. The software also must contain the anatomy and abutment library. The emergence profile of the crown or bridge is designed according to the instructions given to the laboratory and based on scanning of the emergence profile. In general, we try to support and perfectly seal the interface between the bed and crown in order to guide tissue healing and maturation.

Because the digital impression may be obtained directly from the implants or from the abutment and depending on the implant system and CAD library used, it will sometimes be necessary, in the lab, to cement the machined titanium bases, represented on the CAD libraries, to the PMMA prosthesis.

The great advantage of CAD is that we can easily modify any parameter of the design later on, e.g., changing the emergence profile design, increasing or reducing its geometry to model the tissues and produce new provisional prostheses. In this way we can secure the best clinical outcome, modifying the esthetics and position of the teeth (Joda and Bragger 2015; Joda et al. 2015; Kapos et al. 2009; Kapos and Evans 2014) (Figs. 24 and 25).

Production: Hardware and Software

Once the design has been created, work moves on to the production machine, which comes with its own software for this purpose. The two current options comprise digital milling machines and digital printers. Thus, the provisional prostheses could be obtained by milling a PMMA block or disk with a milling machine or printed in a hybrid resin material.

Talking about temporaries, it is important to note that it is not necessary to print a model. PMMA temps are processed as a monolithic material, and therefore the lab technician does not need a model as only minor characterization and bridge modification is needed (Figs. 26, 27, 28, and 29).

Provisional Prosthesis

Usually temporary bridges are made of polymethylmethacrylate (PMMA). Its physical characteristics are summarized below:

- Young modulus: 1800–1300 MPa.
- Flexion resistance: 120–148 MPa.
- Crystallization temperature: 105 °C.
- Melting temperature: 160 °C.
- Service temperature: 40–50 °C.
- Thermal conductivity: 0.17–0.25 W.
- Thermal expansion: (50–90) · 106 K (Fig. 30).

The provisional prosthesis not only restores patient oral health on the same day but can also allow us to assess esthetics and function in an easy manner. Based on such assessment, and particularly in the case of full arch rehabilitations, it is common practice to modify the design of the provisional prosthesis and thus fabricate several of them until the definitive provisional prosthesis is defined to be copied to the definitive prosthesis (Fig. 31).

We consider that in order to complete a case in perfect conditions, the ideal approach is to provide the dental labora-

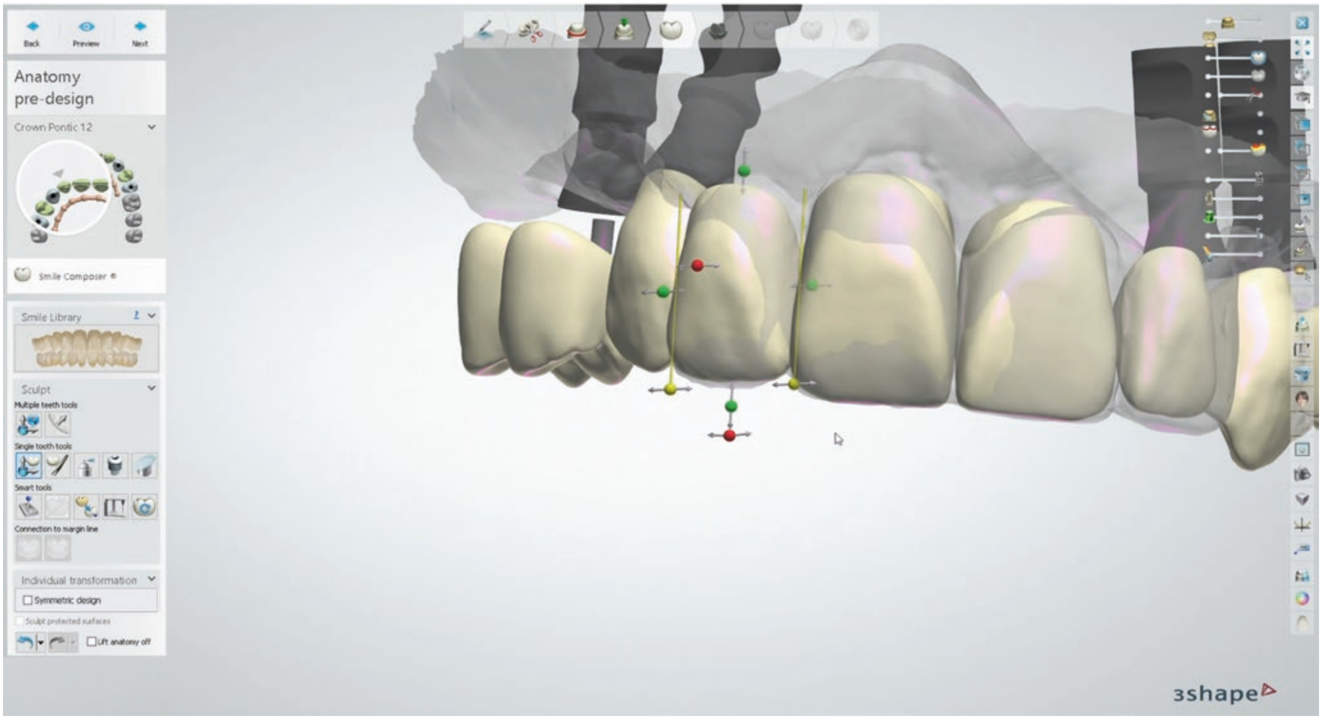

Fig. 24 Image of a CAD design

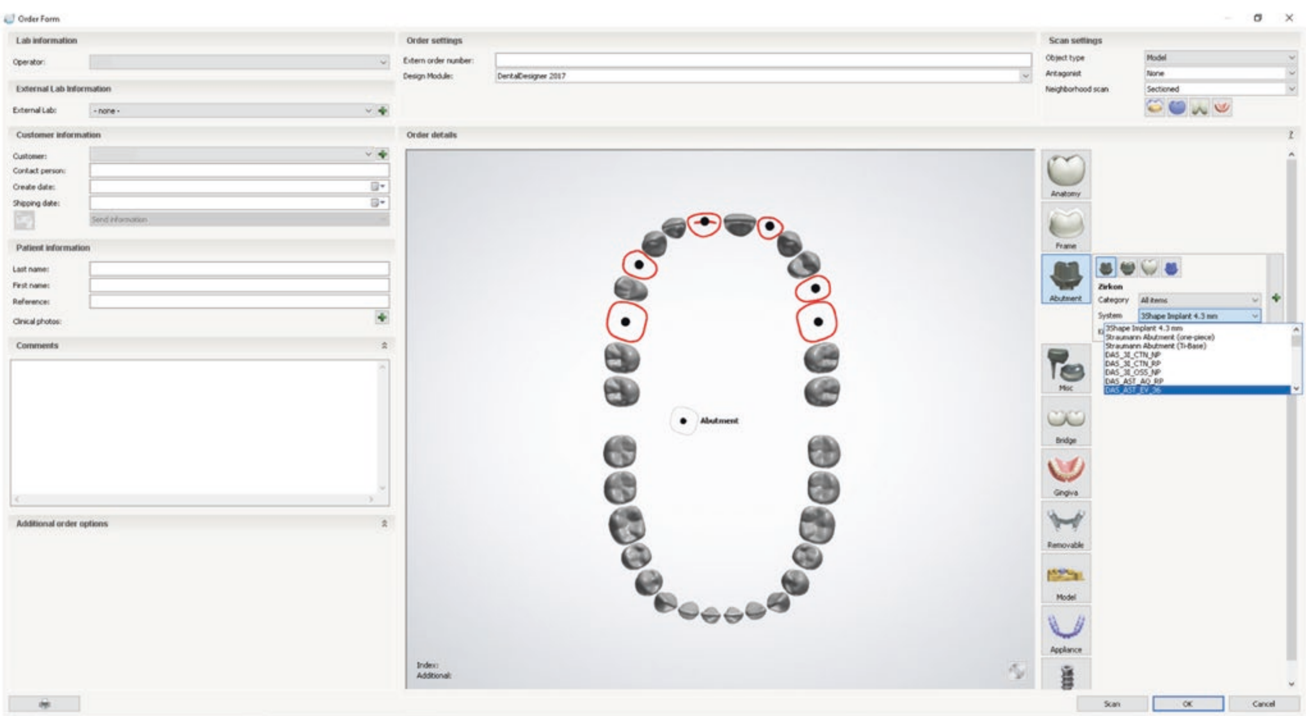

Fig. 25 CAD software. Libraries

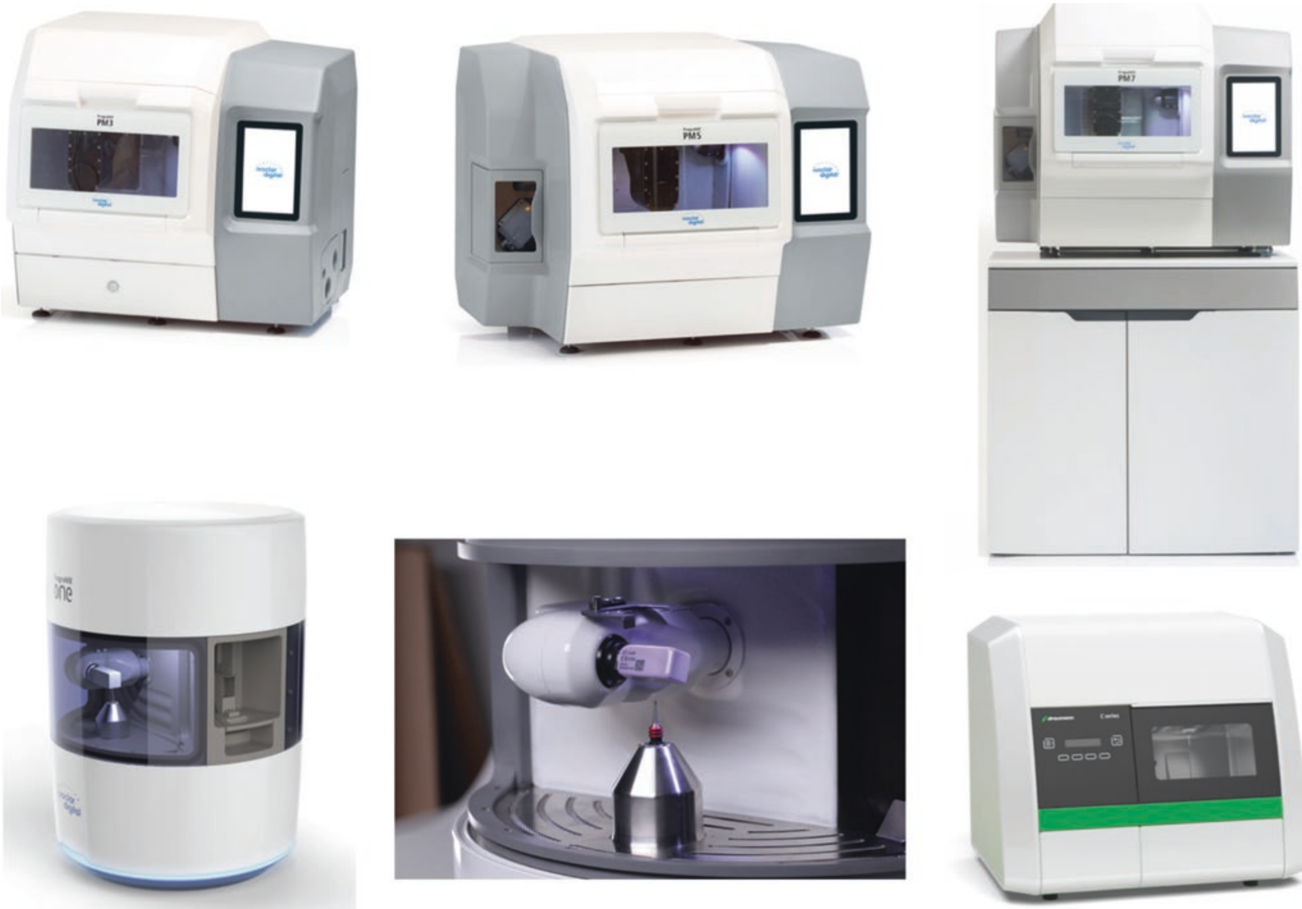

Fig. 26 Some milling machines

Fig. 27 Printing units

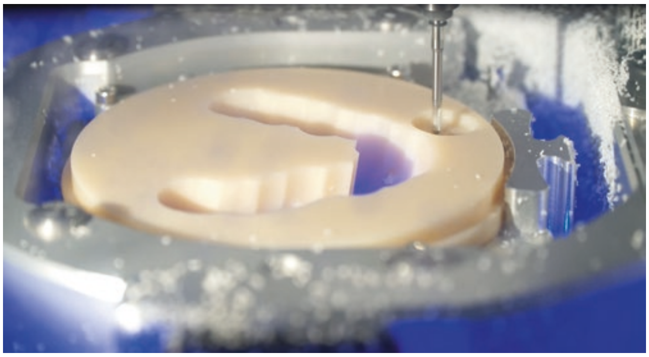

Fig. 28 A PMMA disk being processed on the milling unit

Fig. 29 A PMMA disk with the temporary bridge already milled

tory with all the information it needs for correct completion of the prosthesis. In many cases we deal with prostheses over implants or natural teeth. This implies the need to previously complete the case with a provisional restoration, i.e., producing a provisional prosthesis that satisfies all the clinical objectives of the treatment and the patient expectations.

Currently, the introduction of the face scans, devices that allow us to get a 3D file of the actual appearance of our patient's face, also allowing to merge this face file with different files of the same patient, seems to be the best and simple way to make a correct study and design of a digital wax-up to be copied on this initial temporary restoration. The AFT Dental System is comprised by a face scan, a face scan body, and an intraoral scan body for our patient's dentition under the Facial Flow Concept.

This workflow allows us to register a new perspective of our patient, being able to work with plans and concepts that were created many years ago, and thanks to this technology, we can apply them to our daily workflow in a simple and effective way (Camper, Fox, Frankfurt planes). It allows us

Fig. 31 A PMMA temporary full arch bridge with ti-bases glued, ready to be placed

TELIO CAD PHYSICAL PROPERTIES	VALUES	MEAN VALUE	METHOD
Flexural Strength [MPa]	≥100	135	ISO 10477
Flexural Modulus [Mpa]	≥2800	3106	ISO 10477
Ball Indentation Hardness [Mpa]	≥140	176	Internal Method
Water Absorption [µ/mm^3]	≤ 40	21	ISO 10477
Solubility In water [µ/mm^3]	≤ 7,5	0,0018	ISO 10477

Fig. 30 Properties of the PMMA

to introduce in a simple way new concepts such as the Facial Flow Concept allowing us to make a facial guided dental restoration.

To be able to align two faces with different gestures accurately, this system uses *Face Data*, which consists of two volumetric aligners, with specific shape and color characteristics to be recognized by any 3D scanner with precision. Its special shape and size ensure an exact alignment position between different gestures, also ensuring the exact maxillary merging with those 3D digital faces.

Initially several face scans are taken, lips closed, medium and full smile, with the face scan body in the same position. Then, using the dental scan body, a new face scan is obtained. This creates several face scan files.

An intraoral scan is obtained and, on the dental software, all this files are merged, creating a multilayer file with all the information. Eventually, even the CBCT file of our patient can be also merged.

Also, consider that by obtaining a face in 3D, we record all the essential information of a patient, such as skin color, shape of the face, age, position and deviation of the eyes, position and nasal and subnasal deviation, position and mandibular deviation, position and deviations of the lips in rest or smile position, the condylar axis of rotation, etc.

By using the facial scanner, we obtain a personalized horizontal plane harmonious with patient's face, and by mounting the jaws in a digital semi-adjustable articulator in a correctly and precisely way, we can record the patient's personalized jaw movements which allows us to reproduce them in the definitive restoration, always according to patient's facial esthetics. This workflow is a dynamic tool that allows us to design the digital wax-up of the proposed restoration of our patient, from a static and a dynamic point of view, as said, an esthetic and functional design. Once designed this digital wax-up, a 3D model is printed. Now we have all the 3D information to be copied on our temporary restoration.

Figures 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, and 65 show a complete, same-day full digital case with the AFT system. A patient with an upper terminal dentition has been appointed to a same-day immediate loading full arch bridge. This AFT full digital workflow allows to have a surgical wax-up of the proposed restoration. Implants and extractions are performed and the full arch temporary is placed in less than 4 h from the start of the surgery (Figs. 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, and 88).

Although this chapter focuses on full digital immediate loading in the totally edentulous patient, we also present, as an introduction, two cases of provisionalization over a single implant and fixed bridge.

Fig. 33 Prep X-ray of the patient with the remaining dentition

Fig. 32 The AFT Facial Flow Concept System

Fig. 34 Initial appearance of the patient, with the removable prostheses in place

Fig. 35 Initial appearance of the patient without the removable prostheses

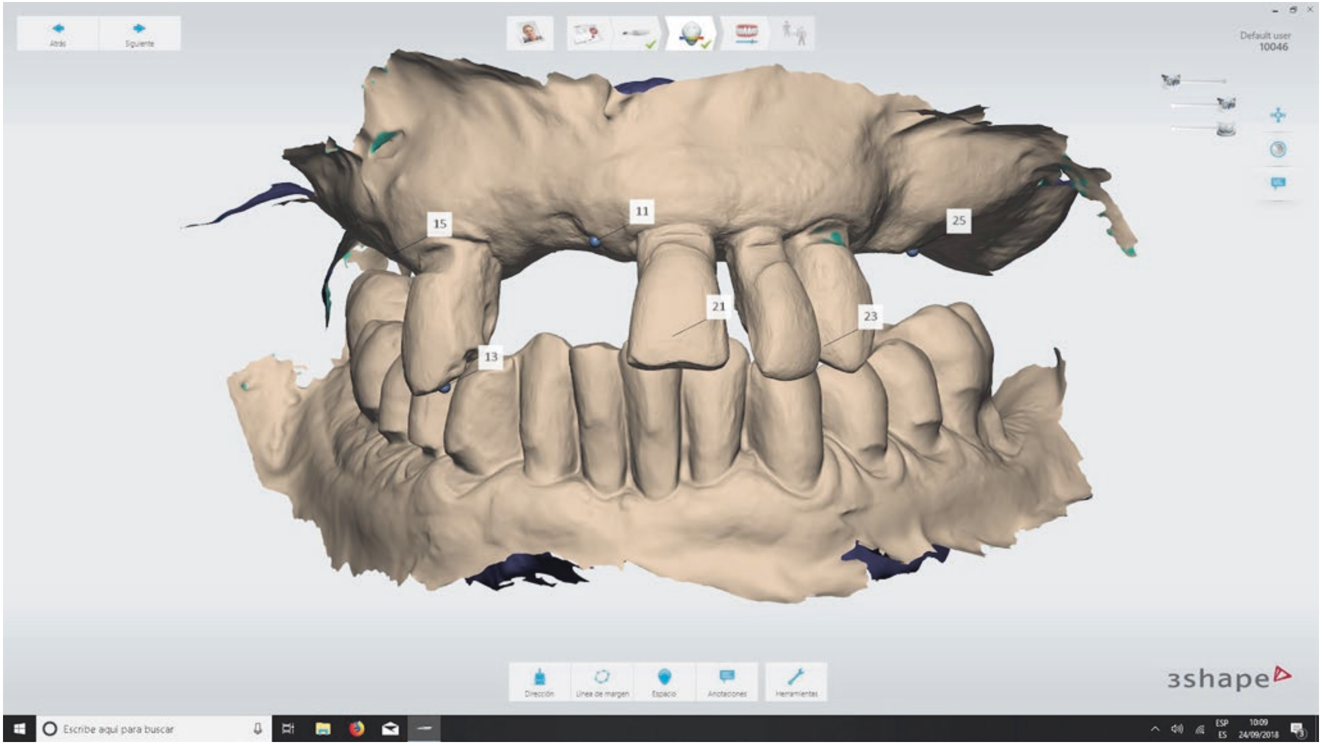

Fig. 36 Intraoral scan of the patient non wearing the removable prostheses

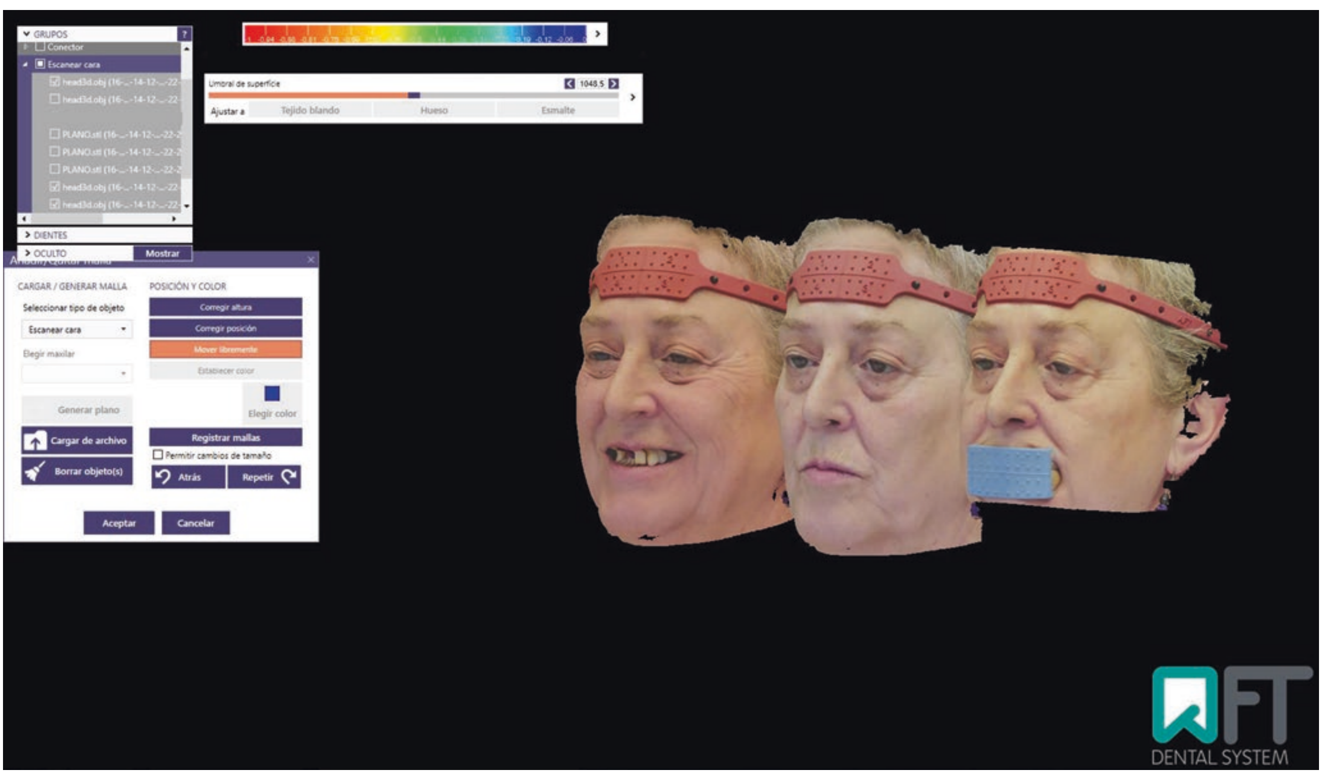

Fig. 37 Face scans once imported on the lab software

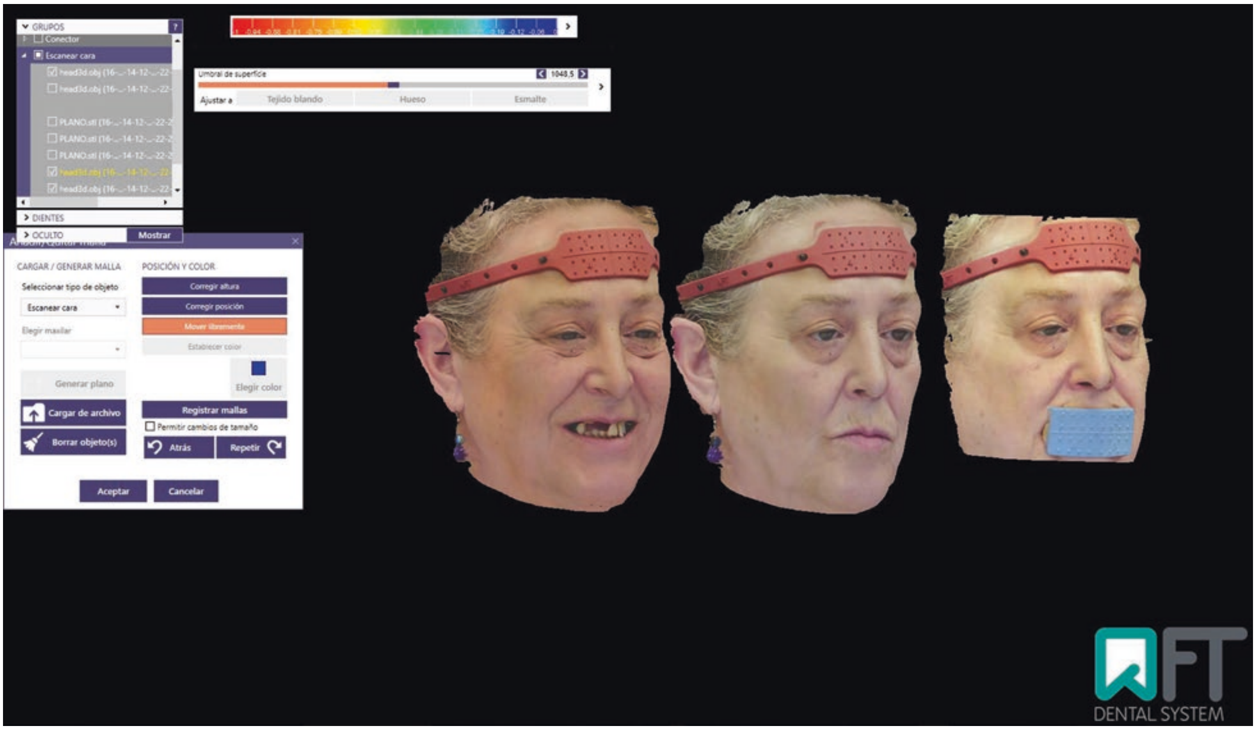

Fig. 38 Different views of the same files

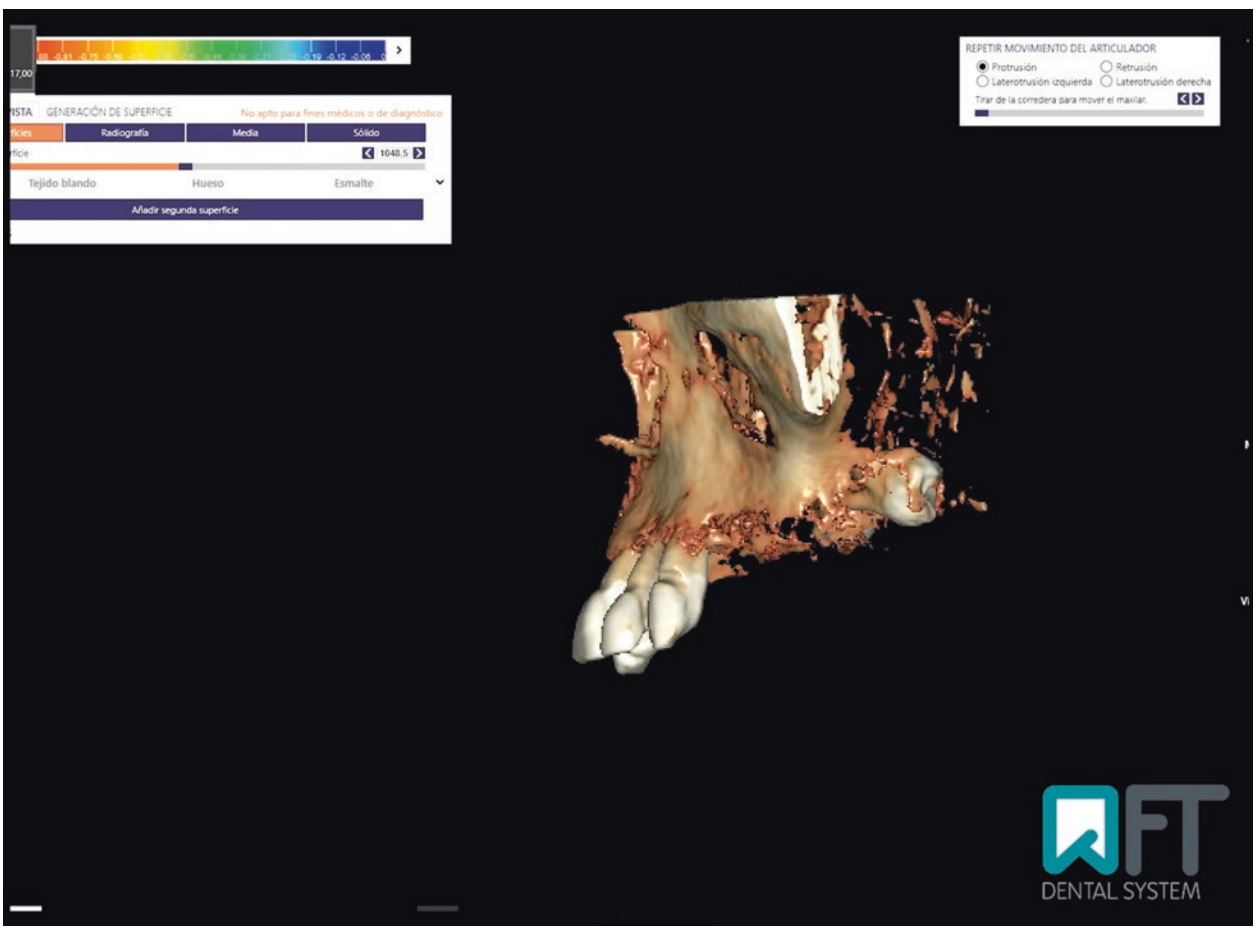

Fig. 39 Patient's CBCT imported

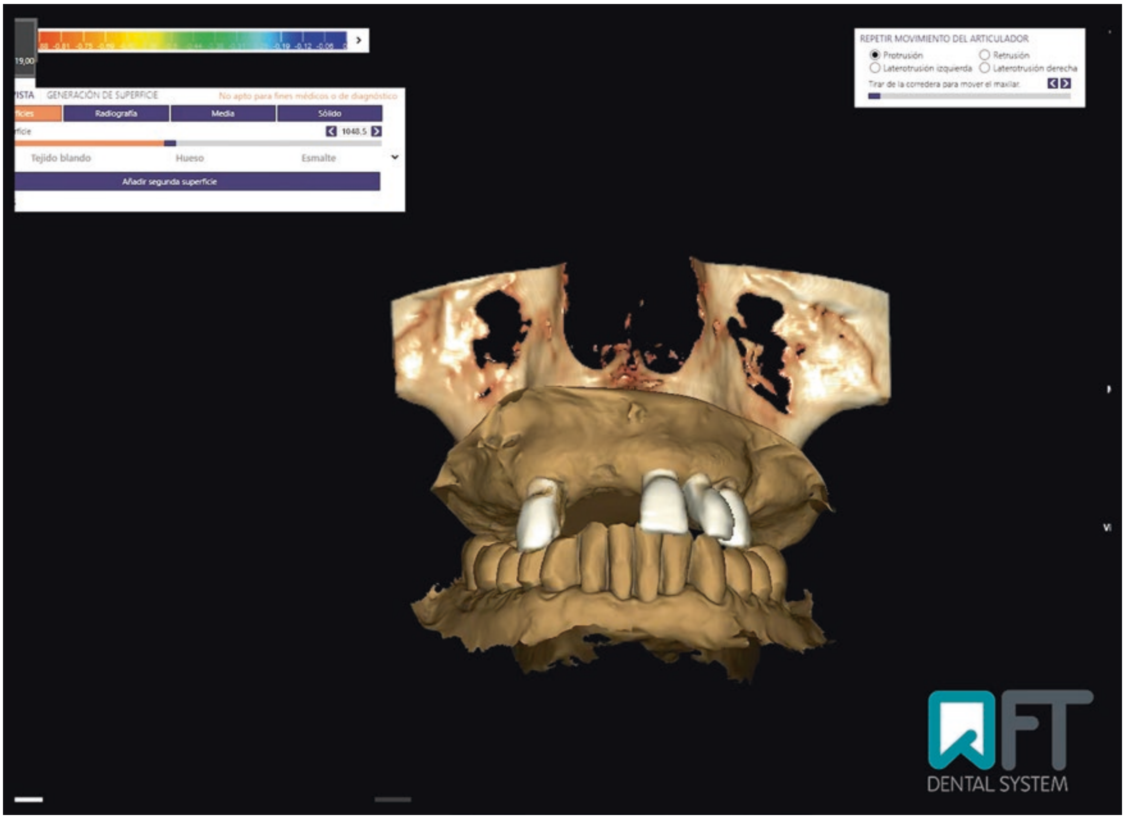

Fig. 40 Intraoral scan file and CBCT file, merged

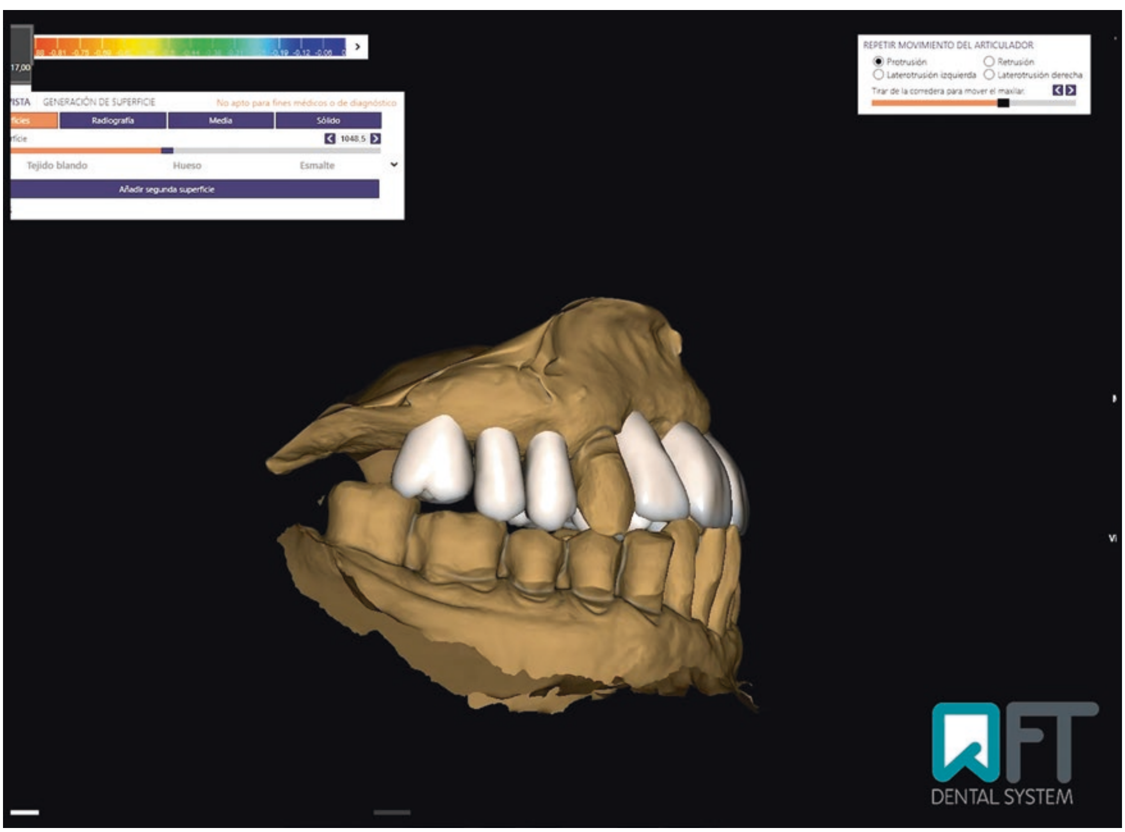

Fig. 41 Initial digital wax-up

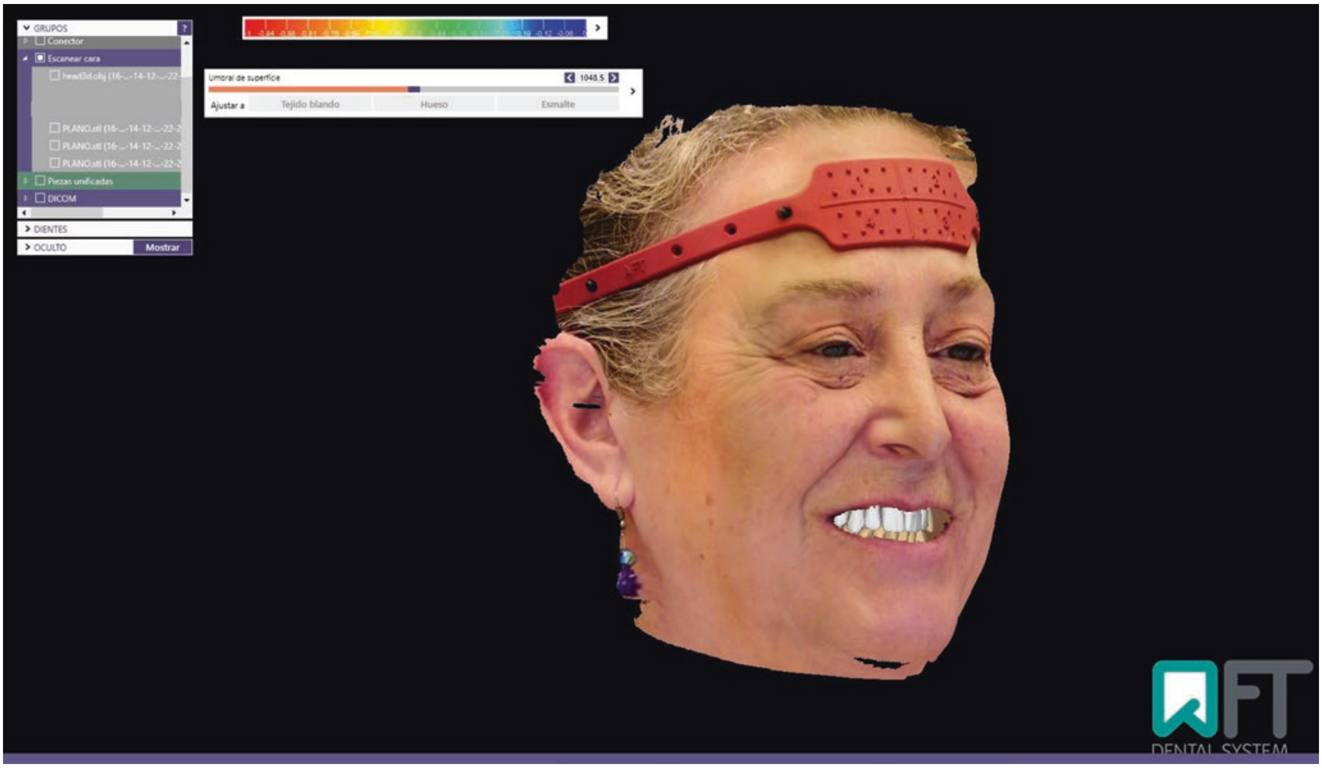

Fig. 42 Appearance of the wax-up on the patient's face and smile. All files are merged

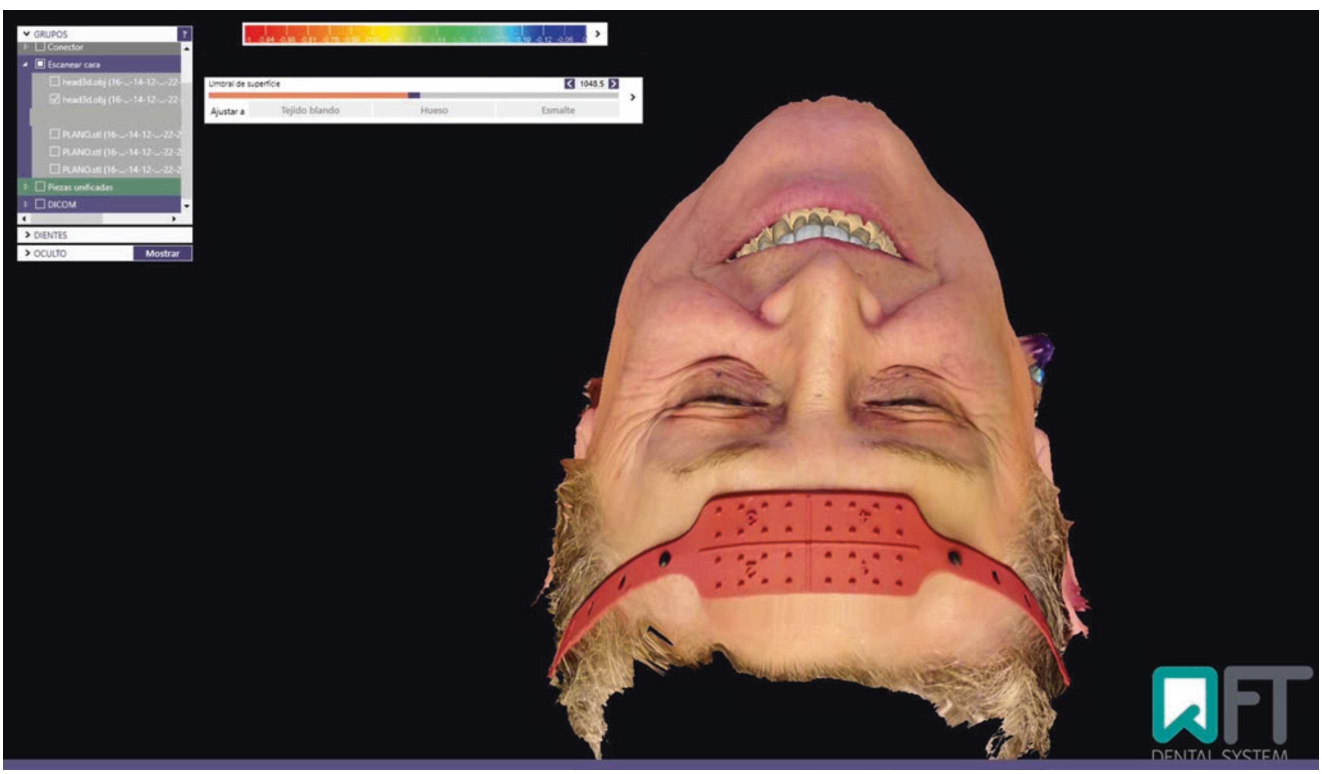

Fig. 43 Looking for the best integration of the midline, this orientation is mandatory to check the real position

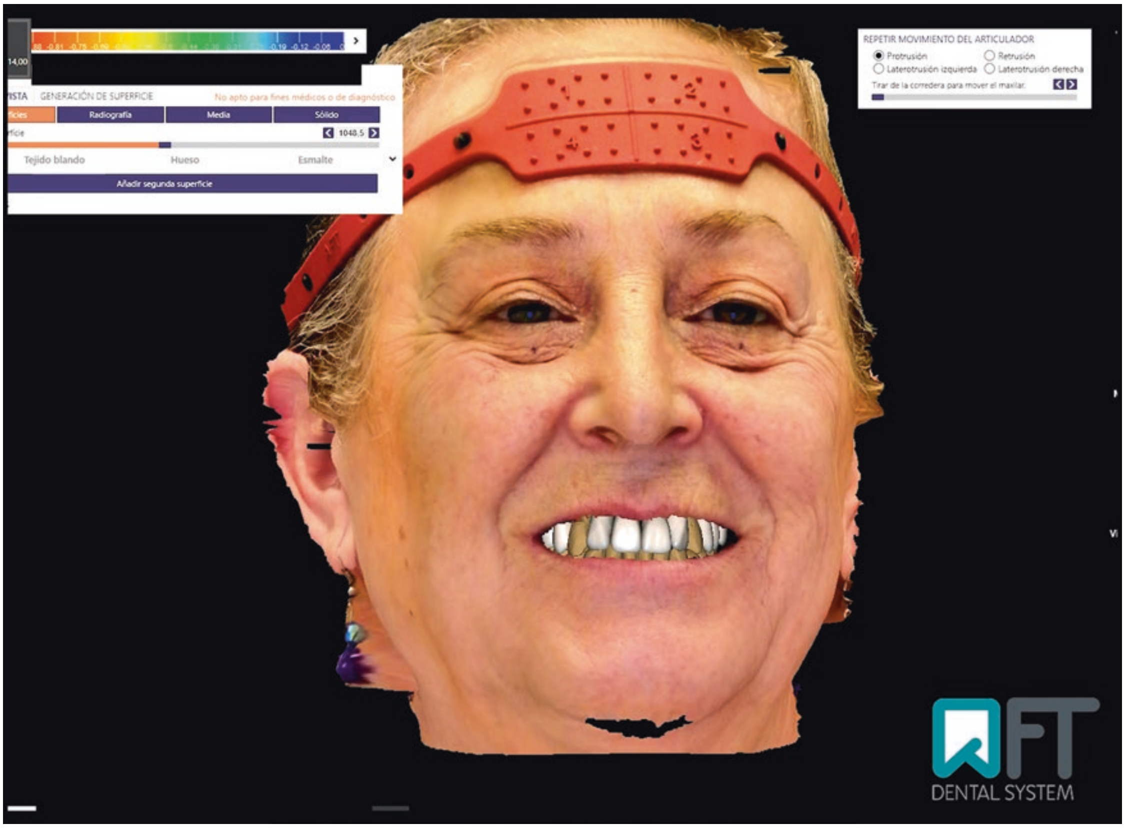

Fig. 44 Appearance of the proposed wax-up on full smile

Fig. 45 Appearance with the lips closed, transparency

Fig. 46 Appearance, full smile, transparency

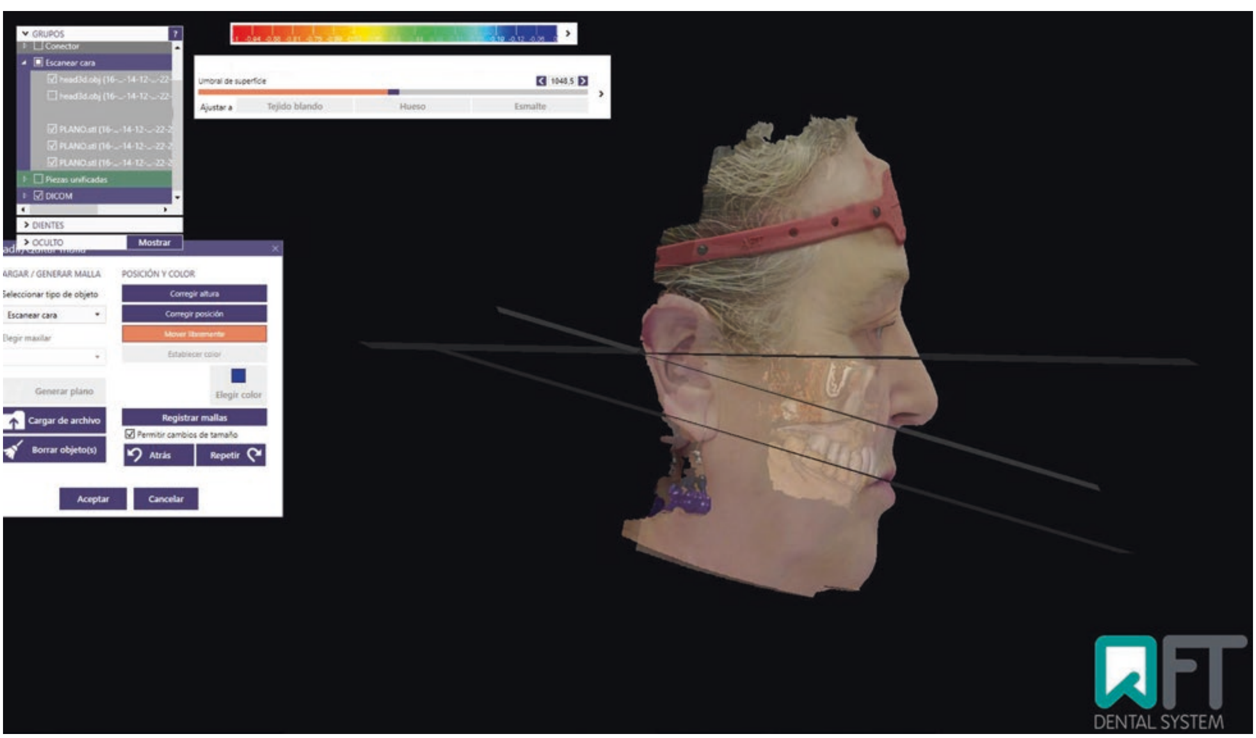

Fig. 47 All planes are aligned to the marked facial skin reference points

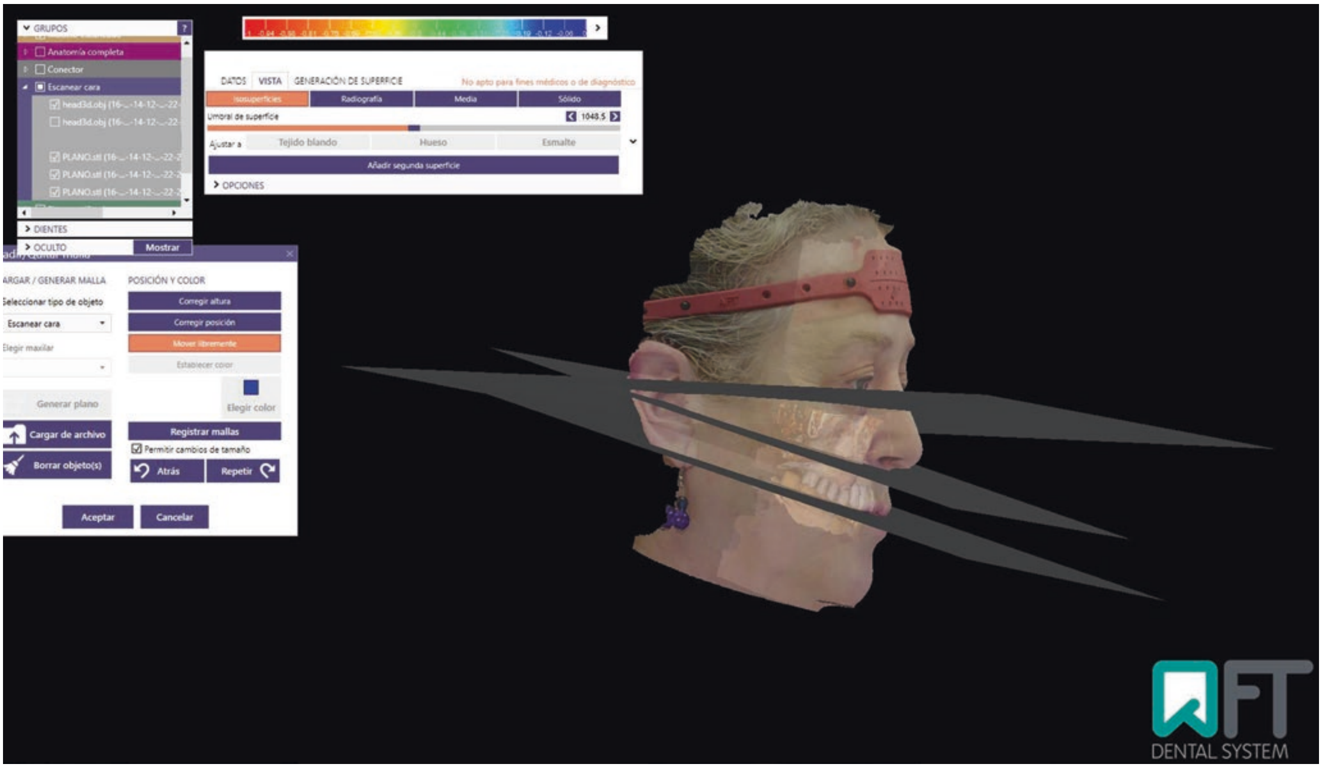

Fig. 48 All planes, different view. Now the functional and occlusion design begins on the esthetic wax-up

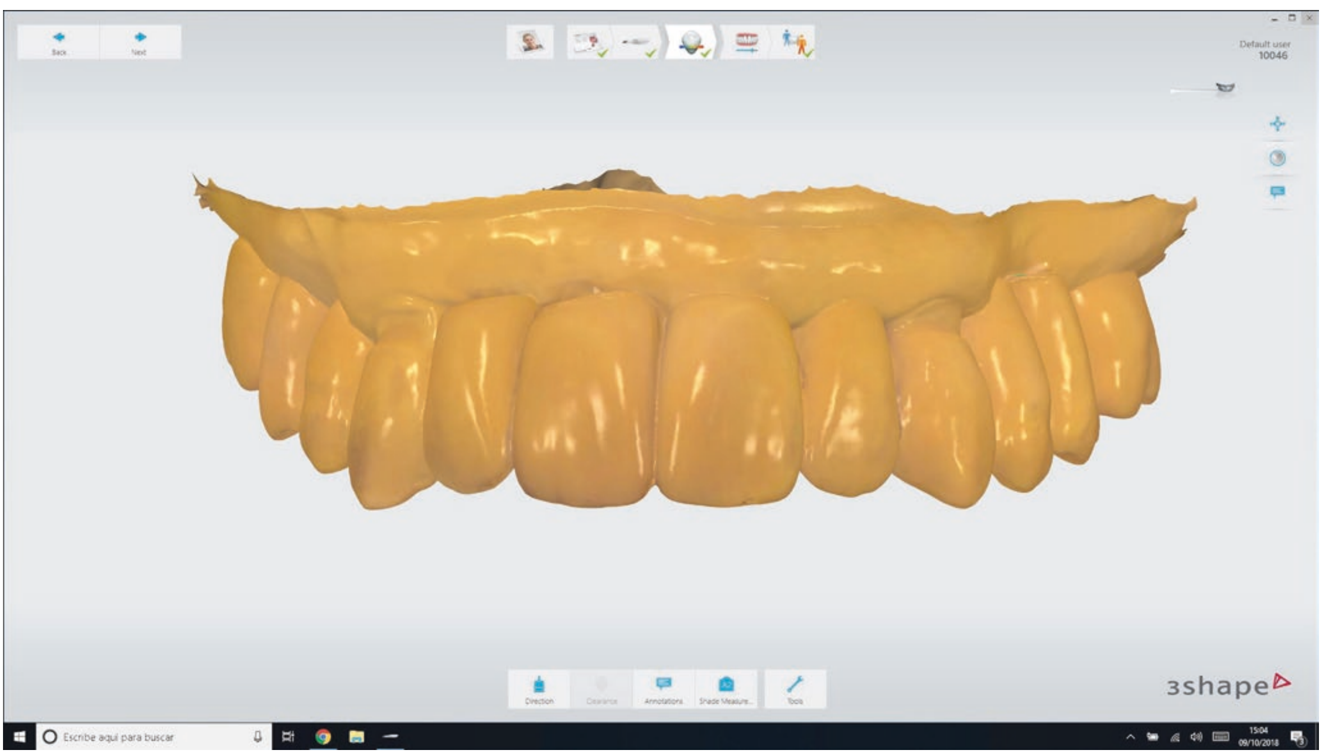

Fig. 49 Once the design is finished, a 3D model is printed. This is the intraoral scan file of the printed model

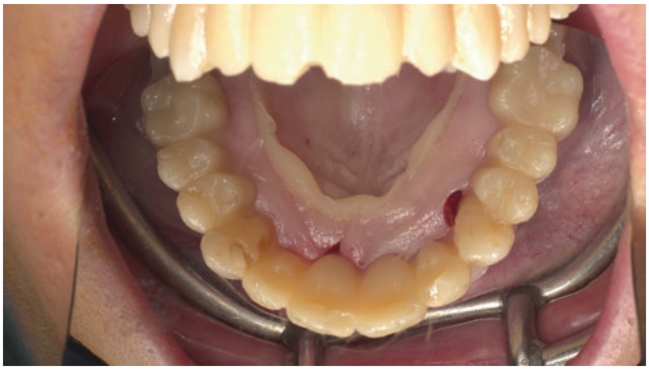

Fig. 50 Now on surgery, by means of the 3D printed model, a conventional wax-up is placed on the patient, after extraction of some teeth, preserving the canines, and scanned again

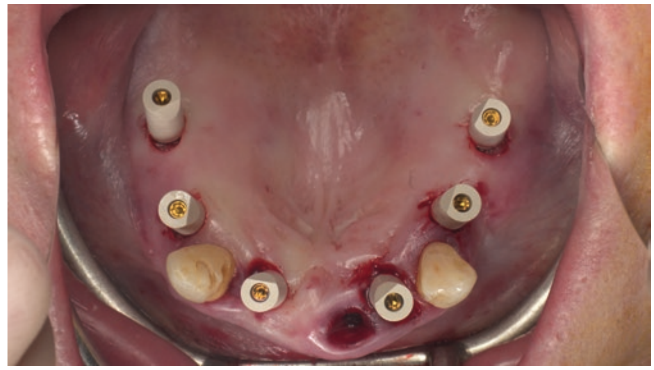

Fig. 51 Only the canines are left in place and implants have been placed with intermediate abutments (insertion torque and ISQ have been monitored). Scan bodies placed on the implant abutments. A minimal invasive surgery, flapless has been performed

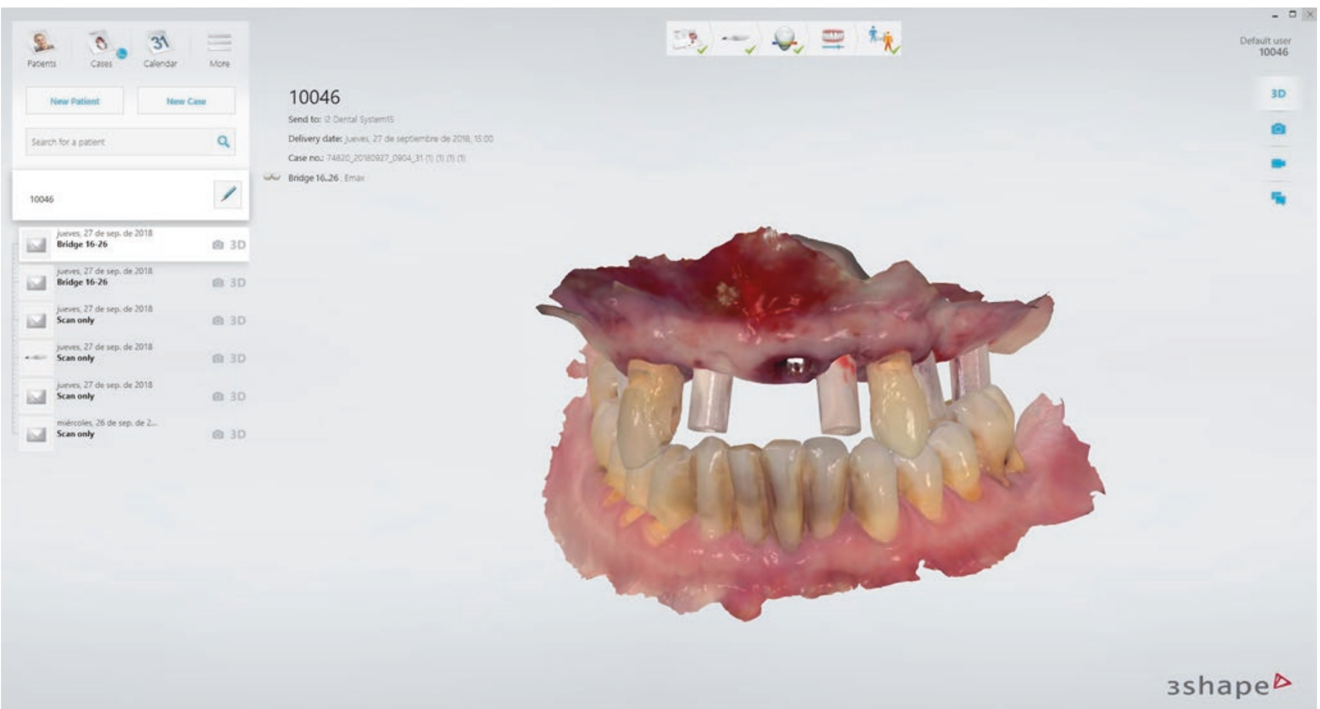

Fig. 52 Intraoral scan file after the surgery

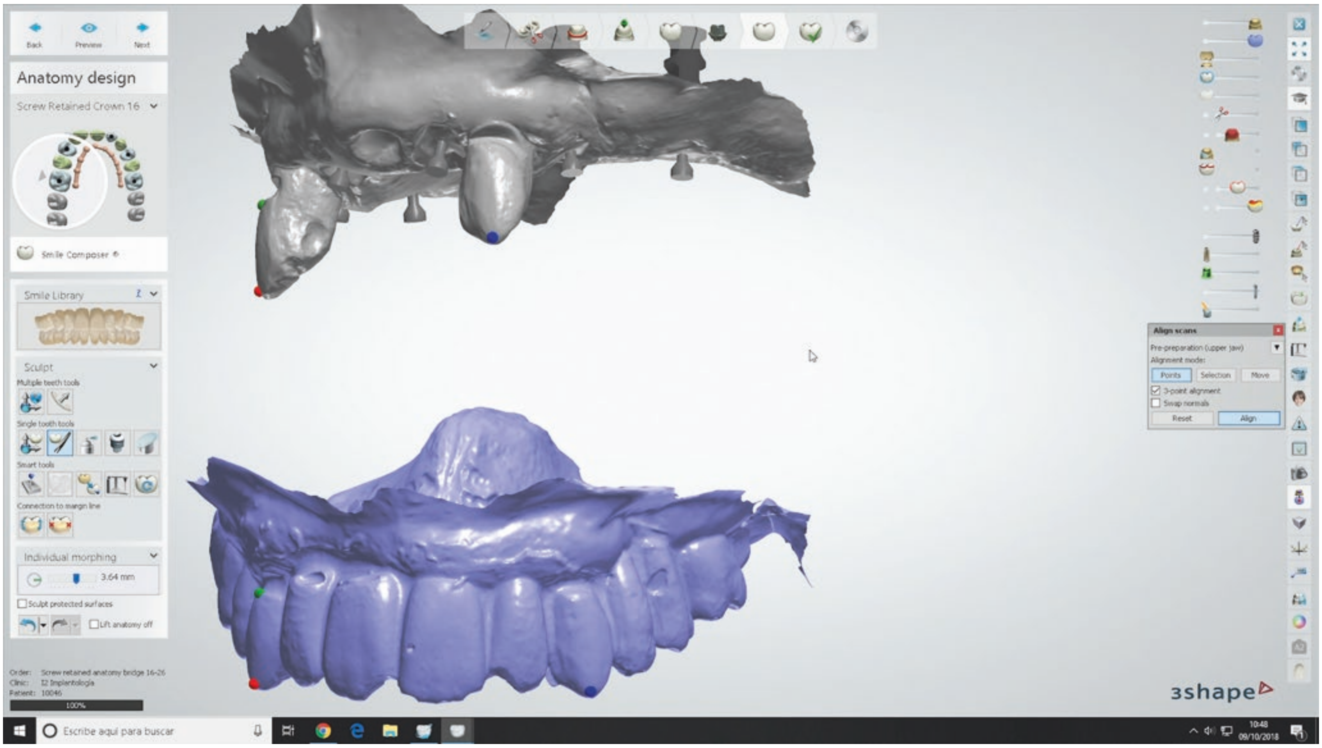

Fig. 53 Both files on the dental lab software: Blue is the preparation scan, the scan file of the wax-up. Gray is the implant scan file. Setting merging points on the canines, present on both files, allows to…

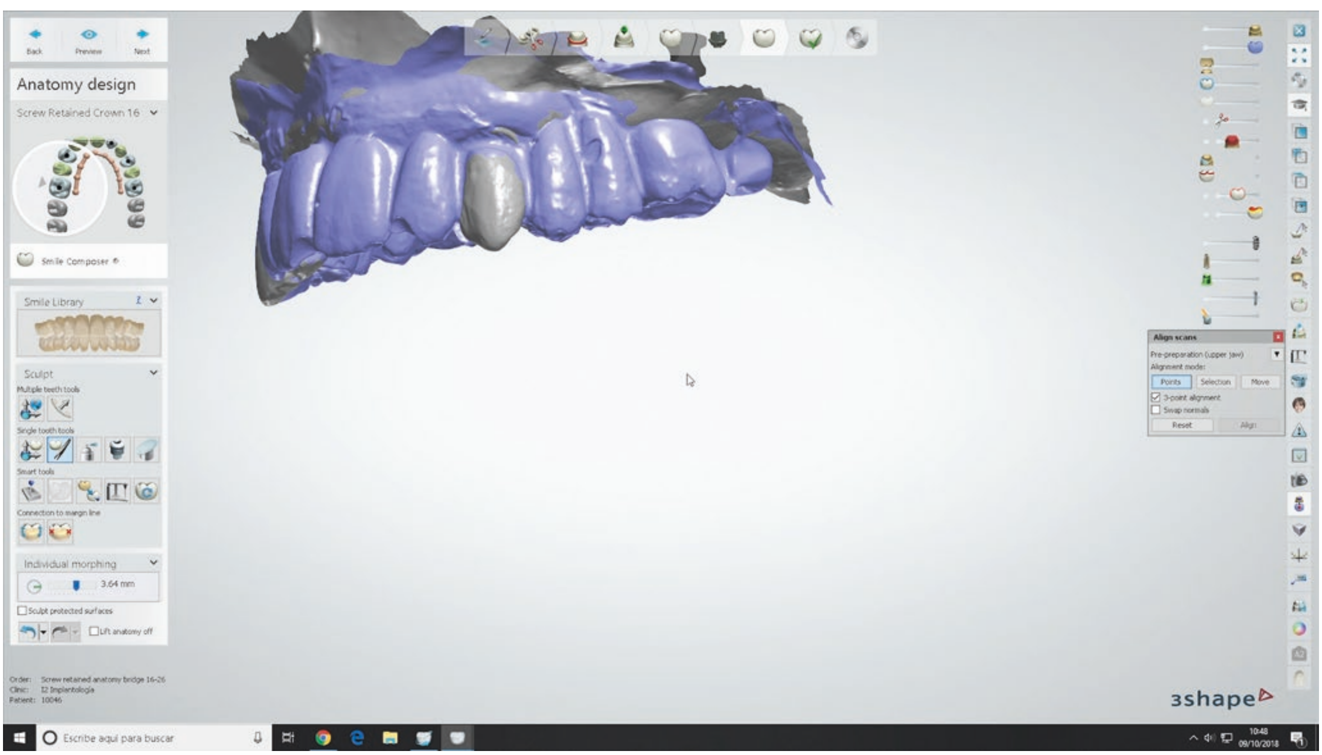

Fig. 54 merge both files. Now the wax-up file will guide the temporary full arch bridge design

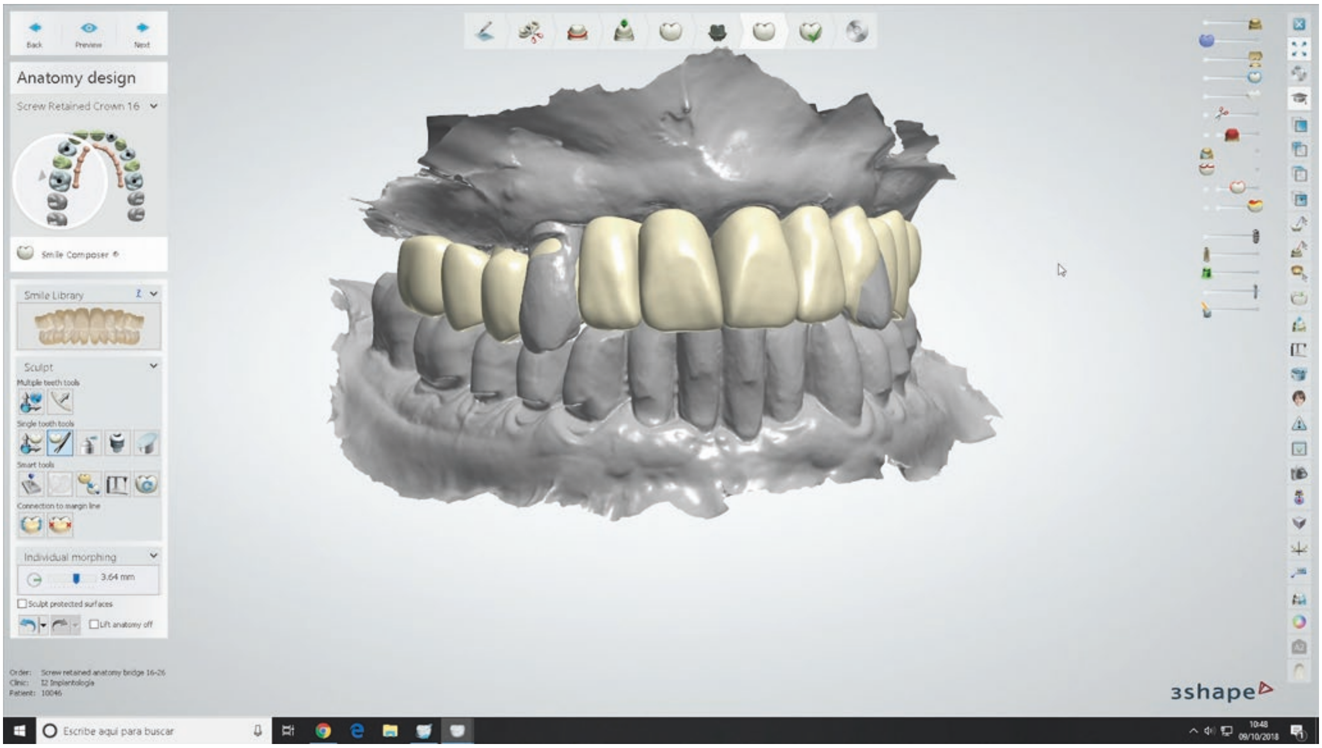

Fig. 55 The lab only needs to copy the same geometrical information provided by the prep preparation, wax-up, blue, scan file

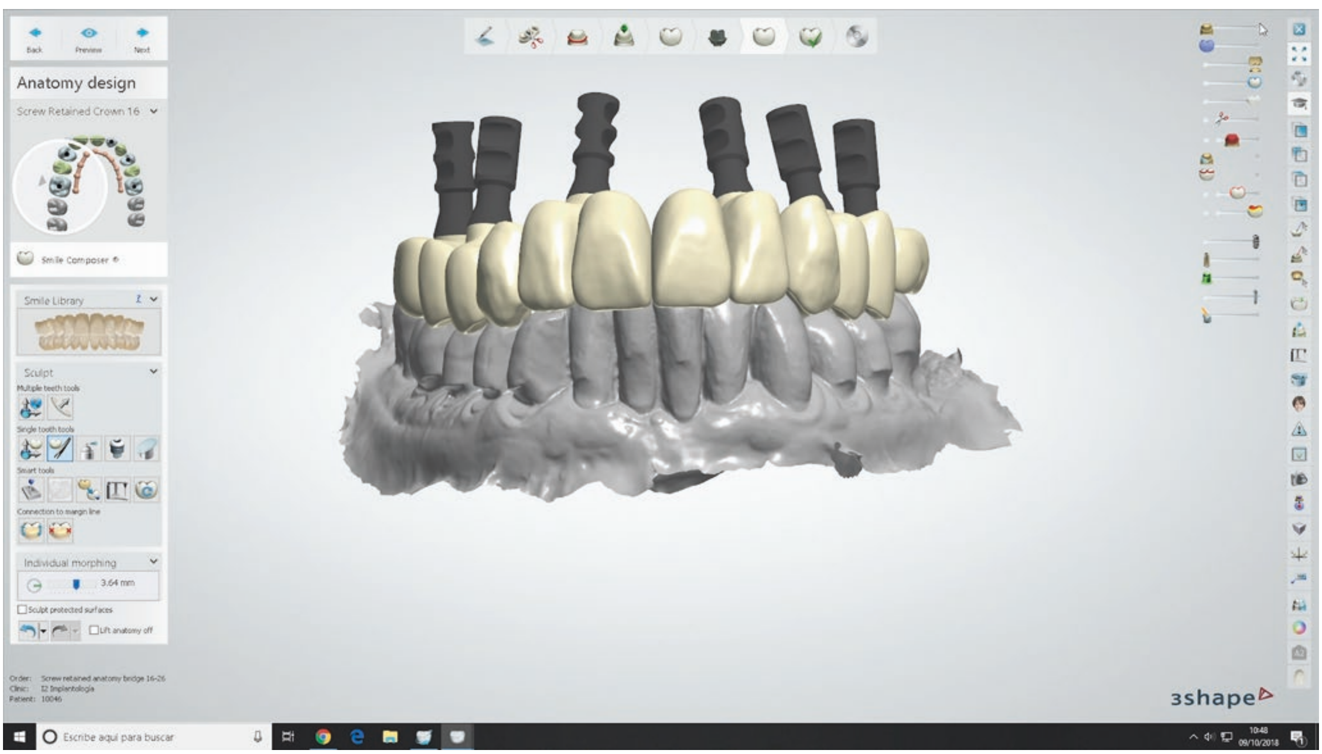

Fig. 56 Designing the emerge profile of the full arch temp bridge

Fig. 57 Once the design is finished, it is milled or printed and, after extracting the canines, tried on the patient

Fig. 58 Now the artificial gum is placed on the temporary

Fig. 59 The best appearance is provided for this temp

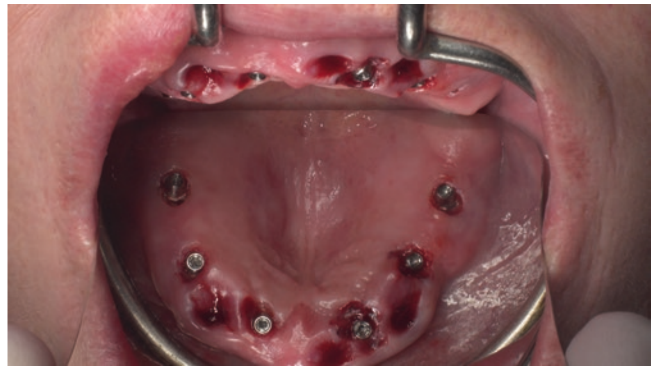

Fig. 60 Intraoral appearance, same day with the intermediate abutments in place

Fig. 61 Close up of the temporary full arch bridge

Fig. 62 Occlusal view

Fig. 63 Immediate, same-day smile of the patient

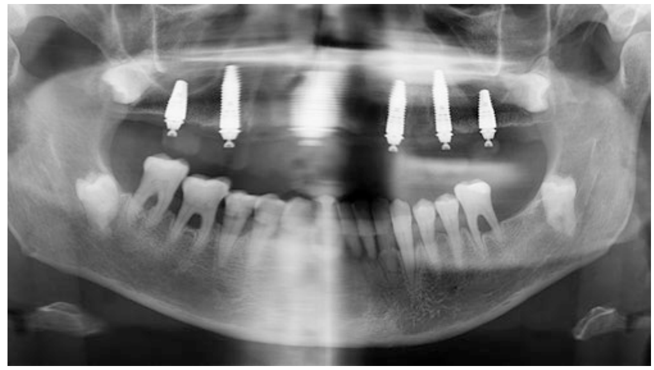

Fig. 64 Post-op X-ray

Fig. 65 Final result with the same-day temporary full arch bridge

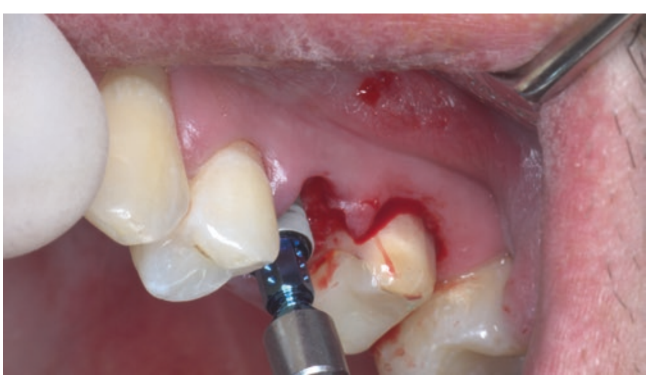

Fig. 66 Single unit case: immediate implant on 25. Implant placement. Also #26 has been prepared and scanned for a final lithium disilicate crown milled chairside. While the crown is being milled, surgery is performed

Fig. 67 Scan body in place (mirror view). Final ceramic crown on #26 seated

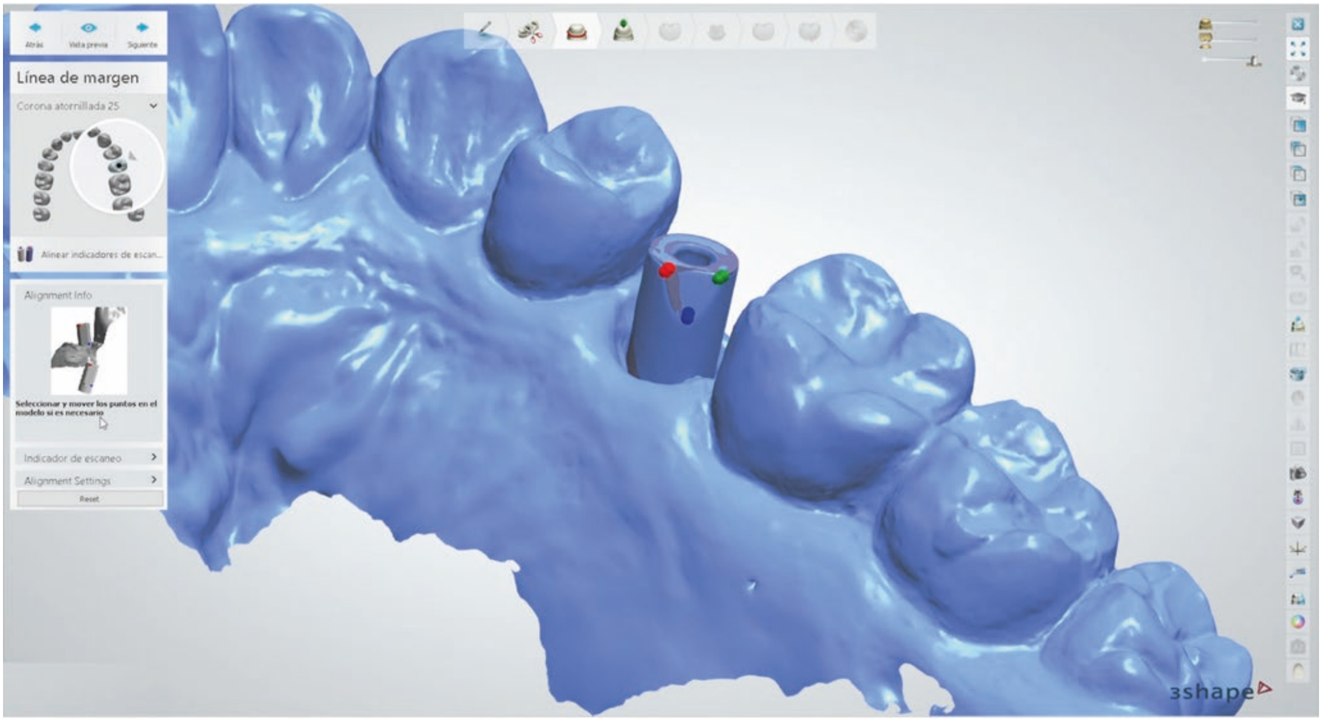

Fig. 68 Scan body best fit on the lab software

Fig. 69 The milled PMMA temp crown, glued to the ti-base ready to be placed 45 min later

Fig. 70 The PMMA temp crown on #25 and the final crown on #26 in place (mirror view)

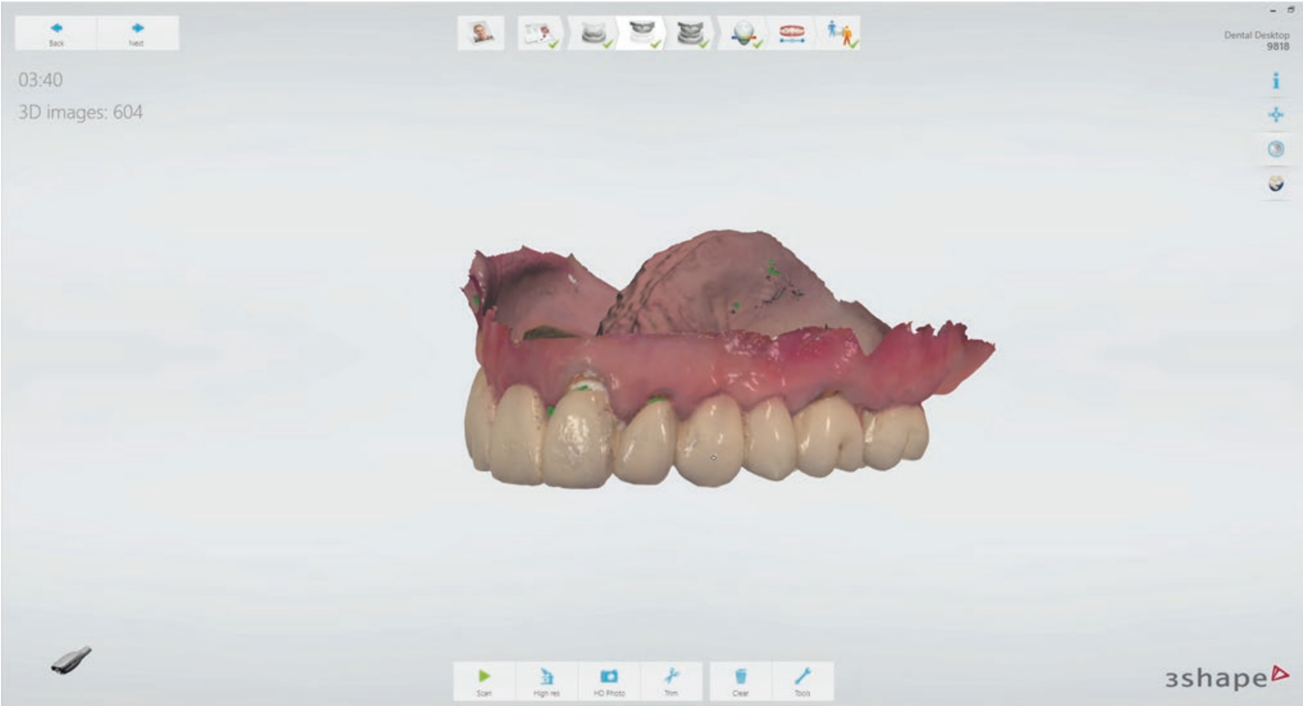

Fig. 71 Failing long upper bridge. Study model scan showing the consultation situation of the patient. This file will be used by the lab to copy esthetics and function

Fig. 72 Surgery: removing the bridge. Extractions of the failing roots and implant placement

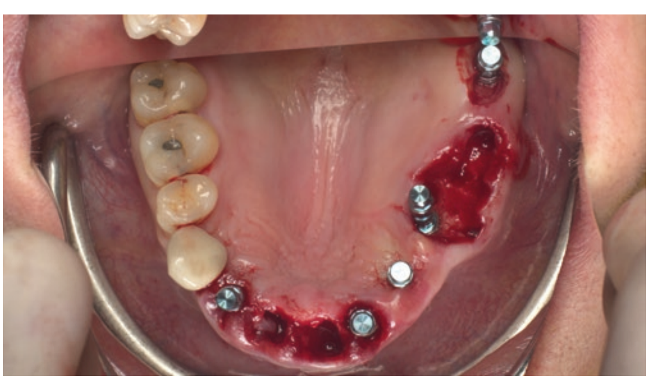

Fig. 73 Implants already placed. Mirror view

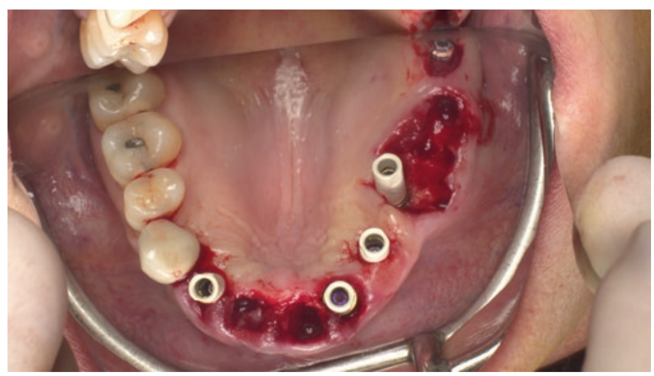

Fig. 74 Scan bodies in place. #28 will not be loaded due to a low ISQ value. A CTG will be placed on #21. Mirror view

Fig. 75 Scan file with implants. Note that teeth on upper right quadrant are present on this file and on the study model (consultation) file

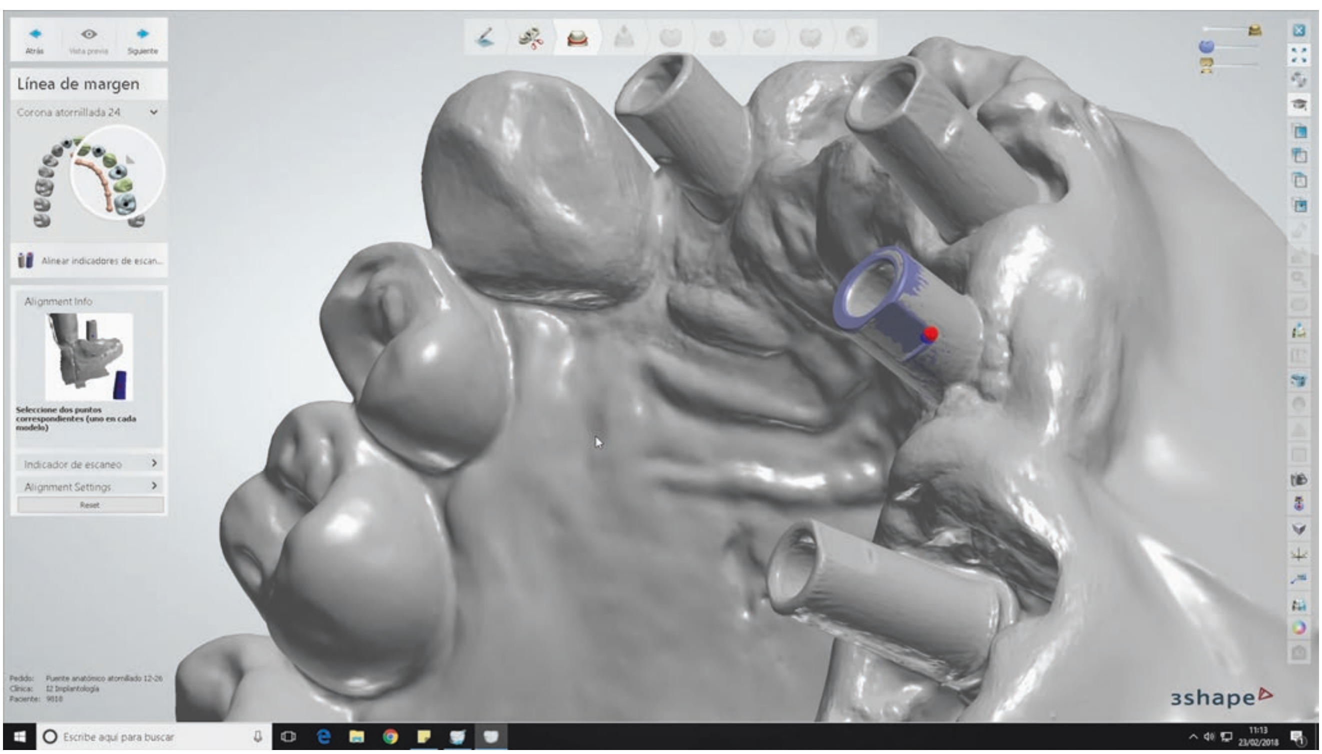

Fig. 76 Implant best fit on the lab. Creating the working file positioning the implants

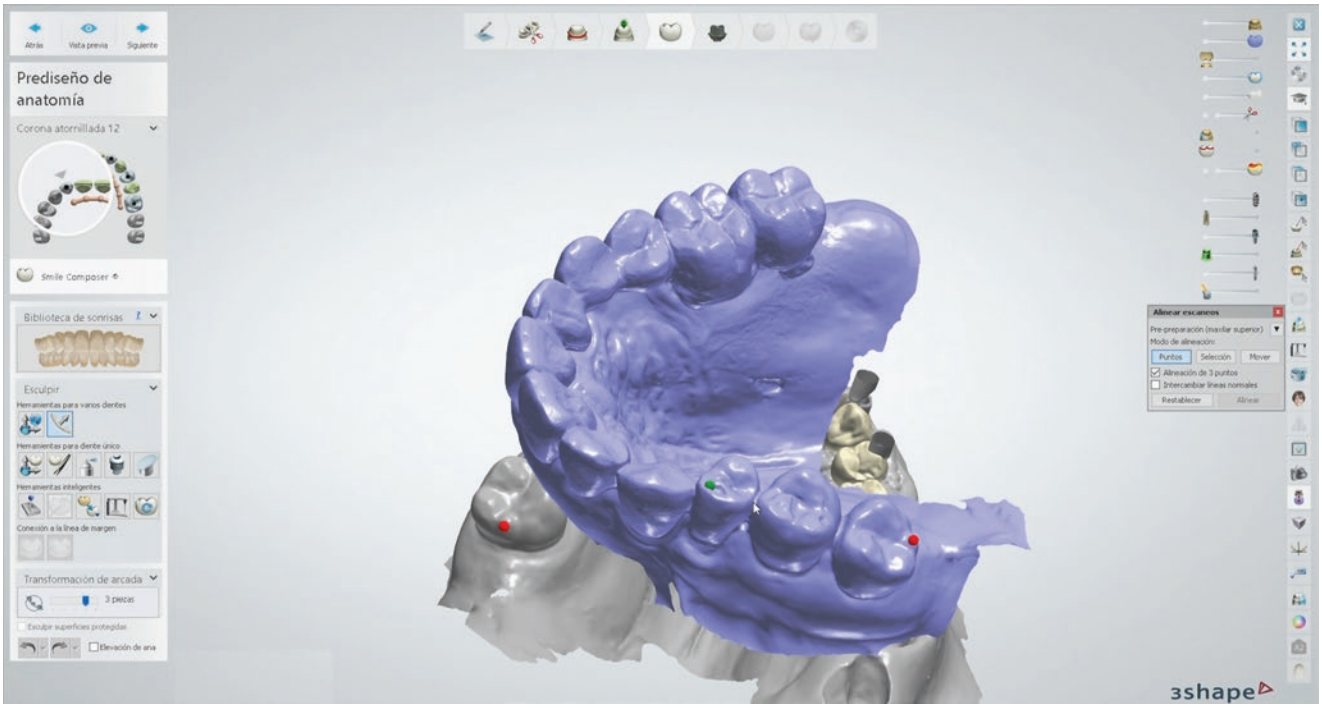

Fig. 77 Marking same matching points on study model scan (blue) and working model (gray)

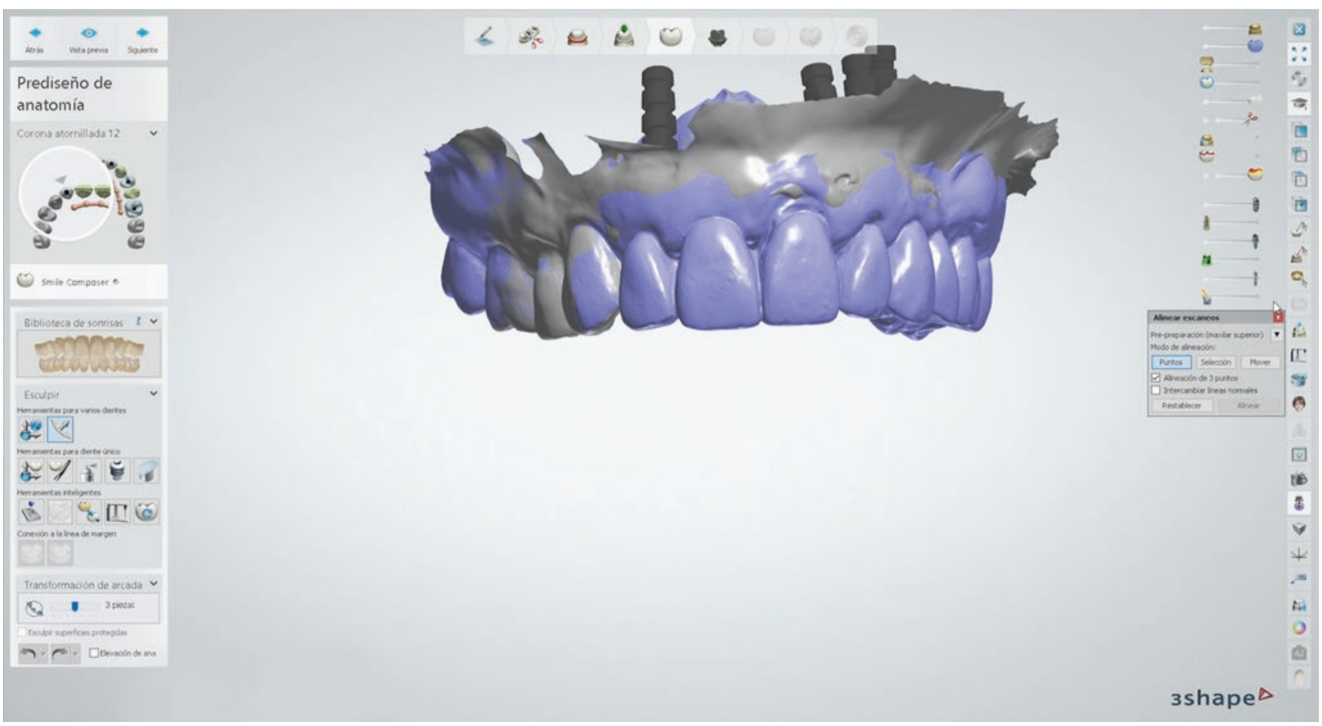

Fig. 78 Both files are merged, creating a single working file (study model file is used as a pre-preparation file)

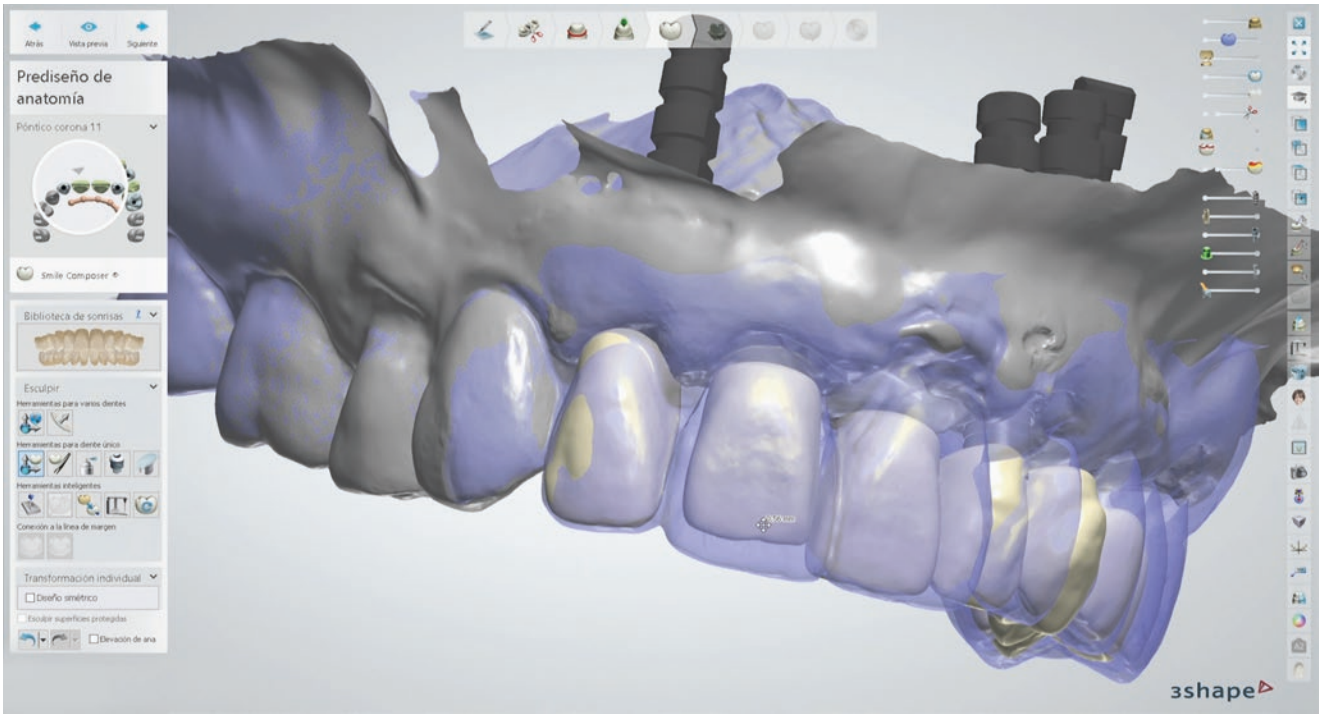

Fig. 79 Easy design of the temporary bridge by the lab using this working file. Just copying the morphology of the failing bridge will provide us an exact copy on temp material to be placed same day. A slight deviation of the midline was present on the failing bridge

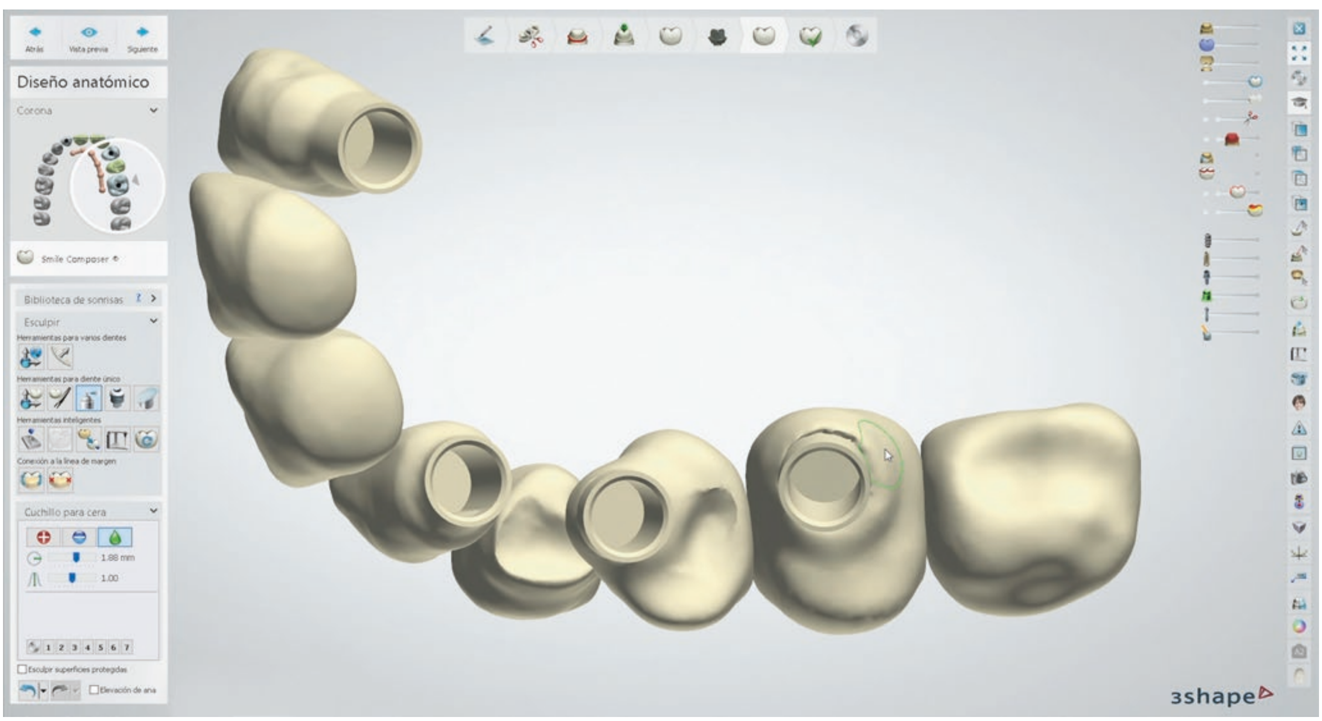

Fig. 80 The temporary bridge file ready to be sent to the milling unit

Fig. 81 Temporary bridge with ti-bases glued to it, same day

Fig. 82 Placing the temporary bridge, direct to implant connection. Screws are placed with the handpiece at 10 rpm and 5 Ncm. After all the screws are placed, torque is increased to 15–25 Ncm

Fig. 83 Final immediate result

Fig. 84 Final immediate smile, 4 h later of consultation. Midline deviation will be corrected on the final bridge because a modification of the #13 crown will be mandatory to redistribute spaces

Fig. 85 Immediate X-ray control showing the perfect fitting of the bridge on the implants

Fig. 86 Four-day evolution

Fig. 87 Four-day evolution close-up. Note the excellent behavior of the soft tissue around the Telio CAD bridge

Fig. 88 Four-day smile

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The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: Non-guided Treatment Protocols

Luis Cuadrado, Cristina Canals Salinas, Cristina Cuadrado Canals, Andrea Sánchez Becerra, and Luis Cuadrado Canals

Take-Home Message
The edentulous patient has become the most common situation in the dentistry daily practice. Patients come to the consultation in order to be rehabilitated as soon as possible to recover their oral health and their self-esteem. This need of having a real and reproducible solution for our patients has driven us to design three new protocols that can be applied daily in the clinic, giving the patient and the work team effective and immediate results.

In this chapter we will cover the different techniques we use for treatment of the edentulous or to-be-edentulous patient on a full digital workflow.

Aimed by the need to have always the some geometrical references and all the intraoral scans of the jaw to be treated, in the same spatial position.

i2 Standard Technique (Figs. 1 and 2)

Applied on a patient with terminal dentition scheduled for extraction (other situations apply such are failing implants).

Our protocol in such cases includes implant placement and the strategic removal of some teeth, preserving temporarily those key teeth which, in the intraoral scan of the freshly placed implants, provide us with the information referred to the esthetics, vertical dimension, and prosthetic arch of the patient. Preserved teeth are present on the study model (consultation scan) and postsurgical (implant scan).

Scanning with scan bodies and teeth is much faster and precise. In effect, the greater the number of three-dimensionally significant structures we have in the mouth, the easier the scanning process and the greater the accuracy achieved. Stitching problems are eliminated from the data registry, and global scan accuracy is incremented, since there are fewer geometrically nonsignificant zones such as edentulous segments and mobile soft tissue.

This protocol (blue side on Fig. 56) comprises the following:

1. Preoperative intraoral scanning (study model) is made with all the teeth scheduled for extraction still in the maxilla to be treated. We also scan the antagonist and bite. This first file (file 1) is sent to the dental laboratory.
2. Surgical phase. According to the preoperative study, we perform the extractions, temporarily preserving those teeth which due to their favorable position will serve as reference, being present in both the preoperative scan (file 1) and in the scan obtained after implant placement (file 2).
3. After implant placement, we proceed as follows:
   (a) A copy is made of the preoperative scan (file 1), erasing the scan of the treated maxilla and preserving the antagonist and the preoperative bite data.
   (b) We then scan the maxilla destined for treatment. The scanner records the teeth we have strategically left in the mouth, along with the scan bodies connected to the freshly placed implants. This yields a file containing not only the scan bodies but also the teeth (geometrical structures) we have temporally left in place (file 2). This file is sent to the dental laboratory.
4. After confirming that the laboratory has correctly received both files, we remove the remaining teeth.

The laboratory thus receives file 1 recording the antagonist, the preoperative scan (the latter being used to copy the anatomy), the occlusion and the interdental relationship before surgery, and file 2 (containing the postoperative scan, with the freshly placed implants and the preserved teeth).

Using the design software with file 2, the technician imports file 1 as pre-preparation, aligning both files and marking matching points on the teeth initially preserved during surgery. In this way the technician has all the preoperative functional and esthetic information of the patient, aligned over the postopera-

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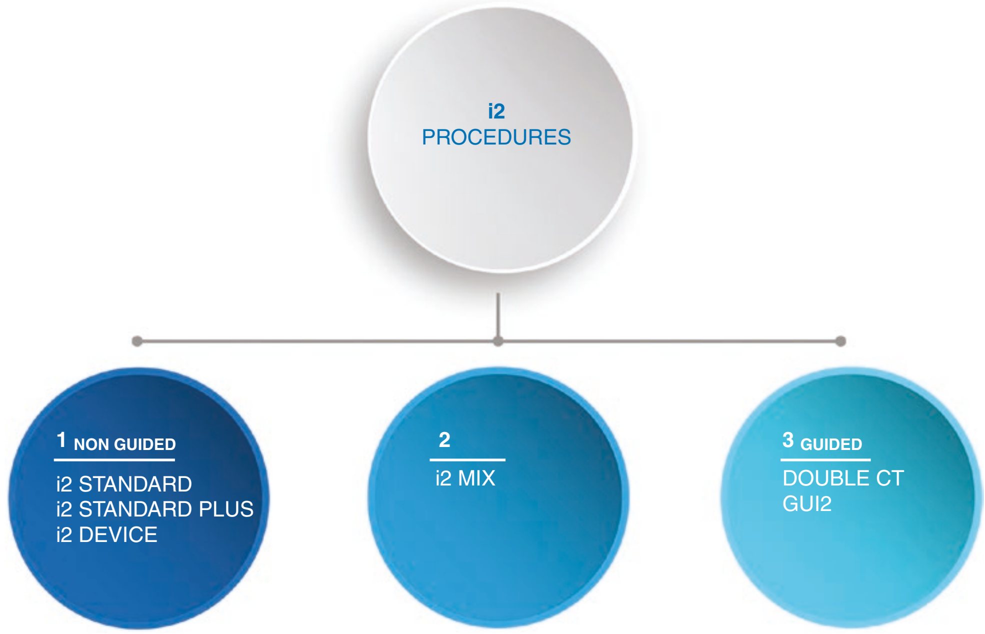
Fig. 1 i2 treatment protocols



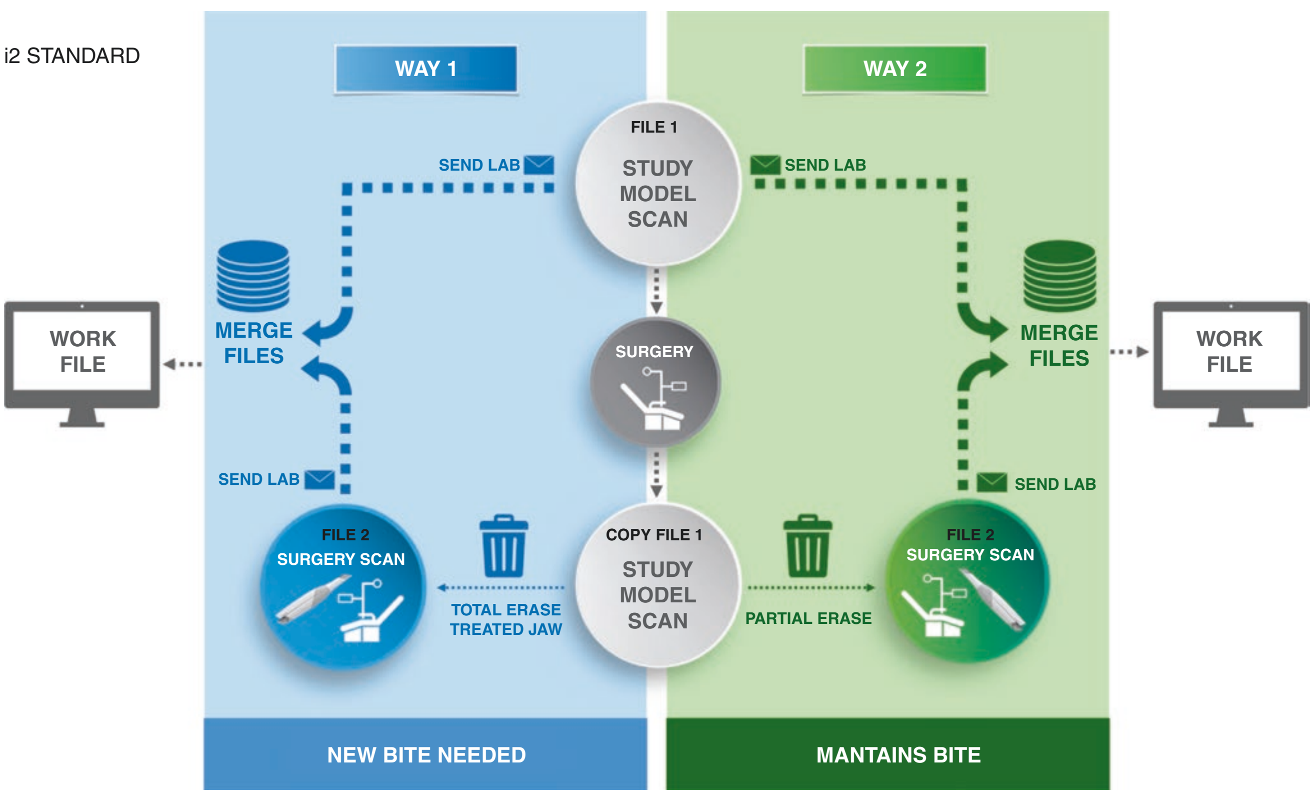


Fig. 2 i2 standard technique flowchart. Two ways: erasing or not the whole jaw treatment scan

tive situation, and is able to copy the esthetic and functional condition prior to the surgical procedure or modify it if needed. Using the laboratory software, the technician performs best-fit matching of the scan bodies on the implants and, with the virtual model thus created, designs the emergence profile of the prosthesis from each implant, as well as the esthetic and functional characteristics of the provisional prosthesis.

Once the design has been completed, the prosthesis is produced from provisional material, processed, and placed in the mouth of the patient.

A second way could be used (green side on Fig. 56) using file 1, just making a copy and, on this copy, only erase, on the treated jaw scan, those treated (with implants) parts of the jaw. Then start scanning again on this file the implants and scan bodies. The main problem with this approach is that, due to the swelling of the soft tissue and the size of the remaining scan volume, it is usually difficult to get an accurate scan. The main advantage is that doing this way, the bite from the study model scan is preserved (Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31 and 32).

Fig. 3 A bimaxillary case. Same-day immediate loading. Preoperative X-ray

Fig. 5 Upper maxilla: extractions performed, keeping in place key teeth. Implants placed

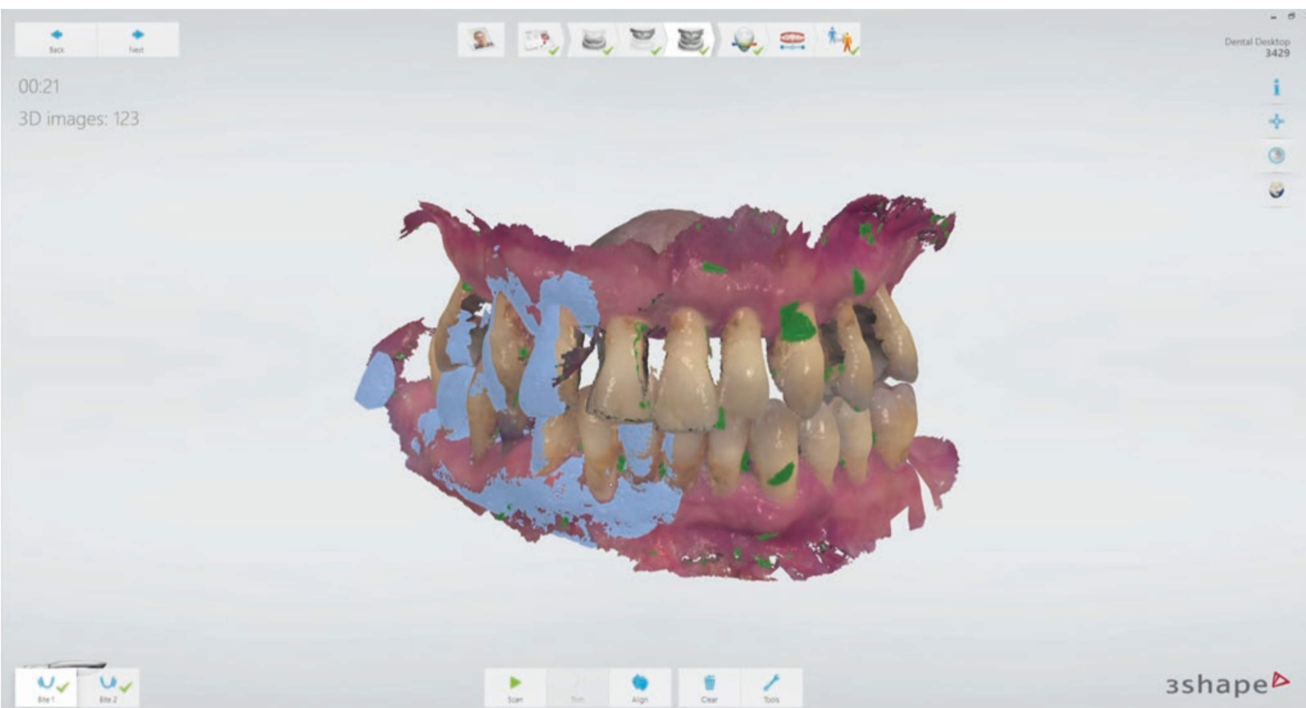


Fig. 4 Study model (consultation) scan

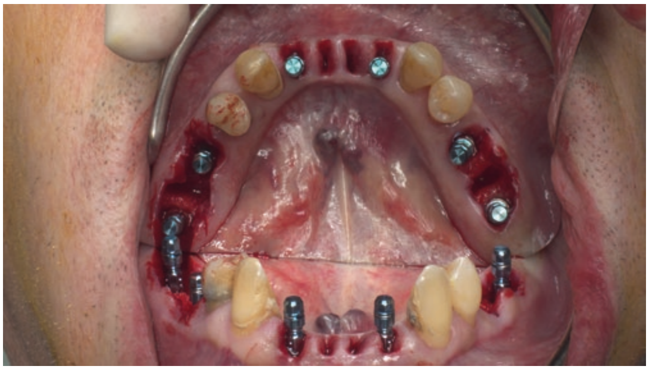


Fig. 6 Lower maxilla: extractions performed, keeping in place key teeth. Implants placed

Fig. 7 Taking ISQ values

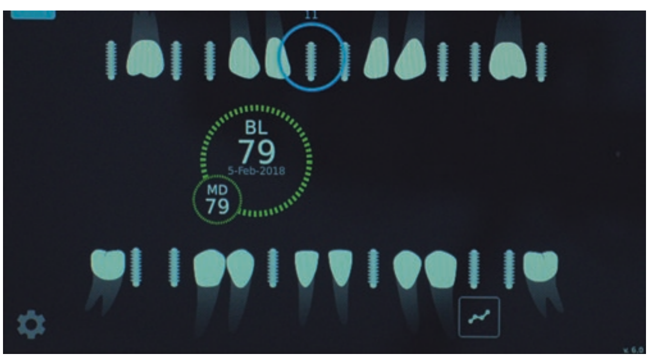


Fig. 8 Taking ISQ values

Fig. 9 Taking ISQ values

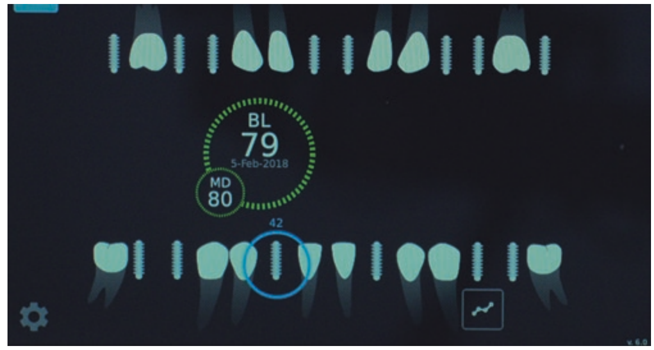


Fig. 10 Taking ISQ values

Fig. 11 Angled abutment placement in 21 and 11

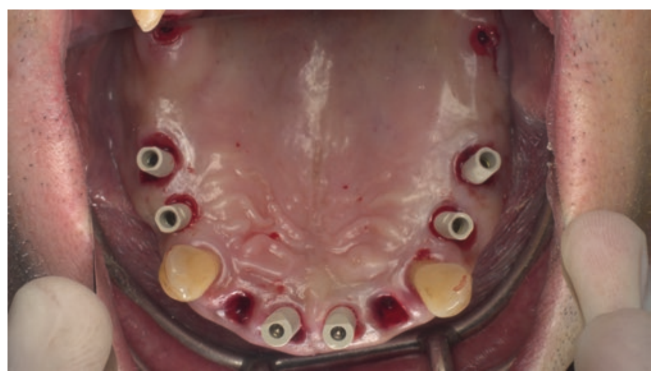


Fig. 12 Scan bodies placed on maxilla

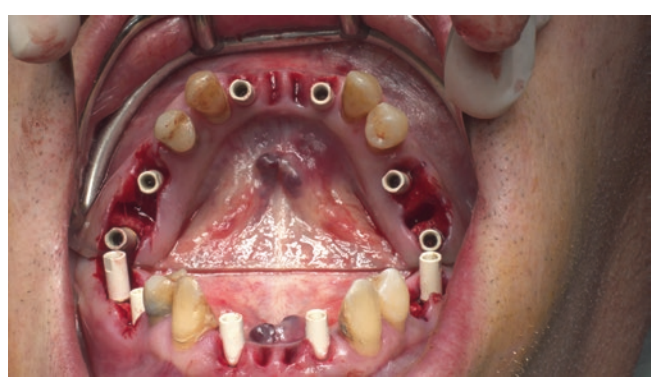


Fig. 13 Scan bodies placed on mandible

Fig. 14 Checking bite, before starting implant scan

i2 Standard Plus Technique

The Standard Plus technique is a variant of the previous technique and is used in cases where implants must be placed in the same positions where the strategically preserved teeth are located.

With this technique we likewise perform a preparatory scan to produce the study model (file 1). The teeth are then removed, the implants are placed, and the scan bodies are connected to them.

A copy is made of file 1, and we only eliminate the palatine/lingual face of the teeth from the scan of the operated maxilla, preserving most of the buccal surface of the teeth.

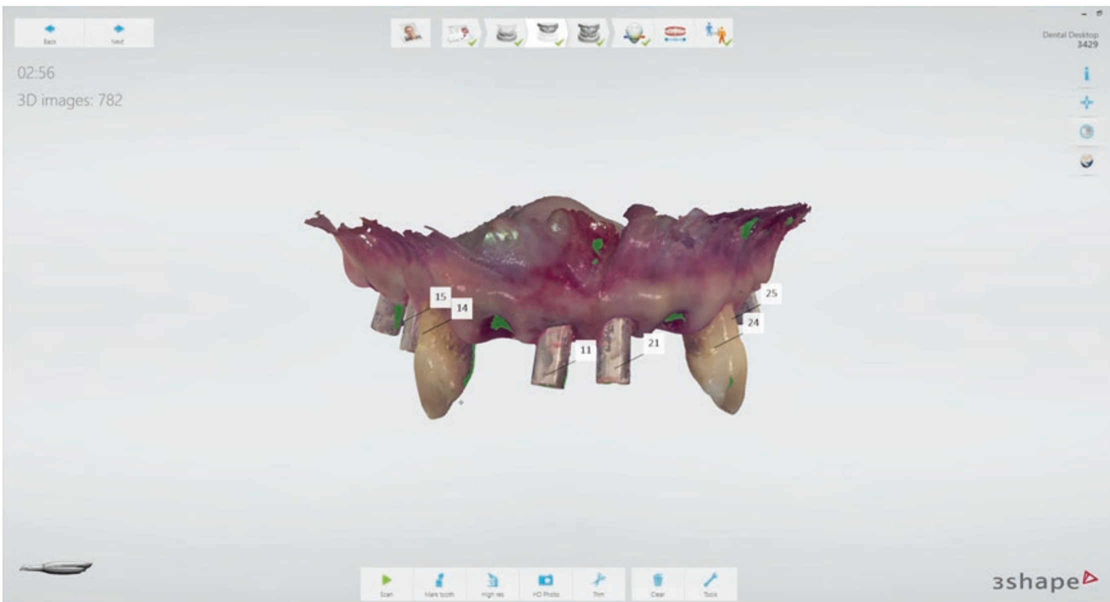


Fig. 15 Maxilla implant scan file

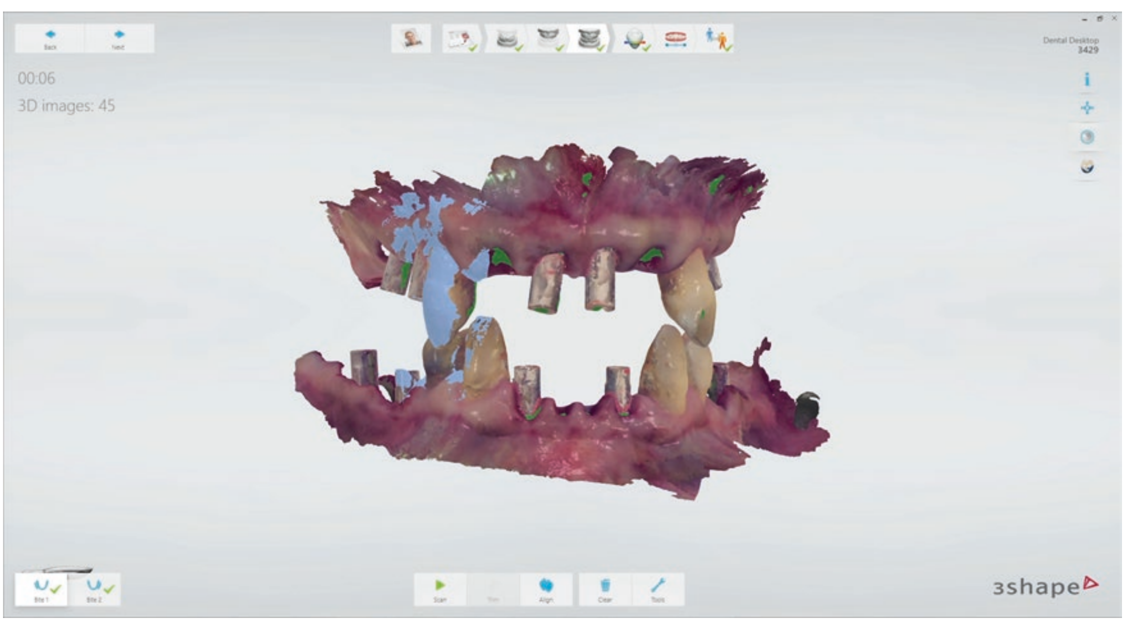


Fig. 16 Bite file, implant scans

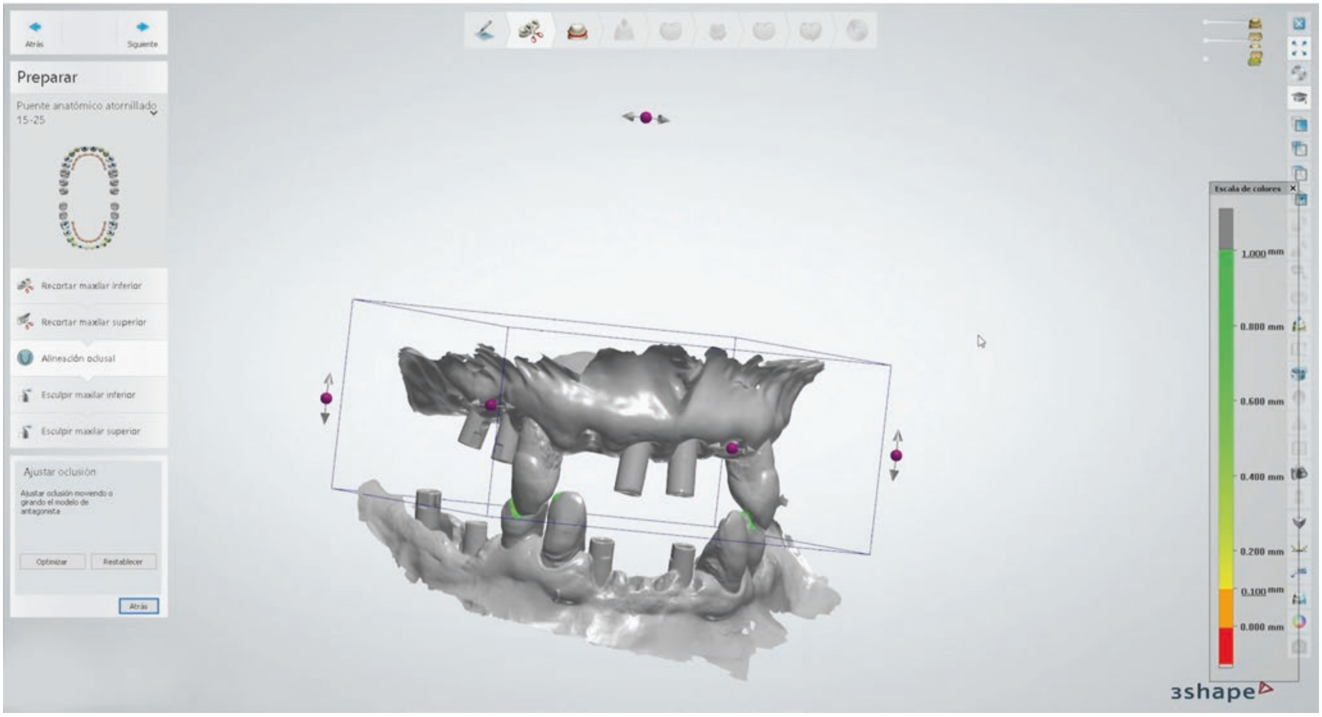


Fig. 17 Working file in the lab software

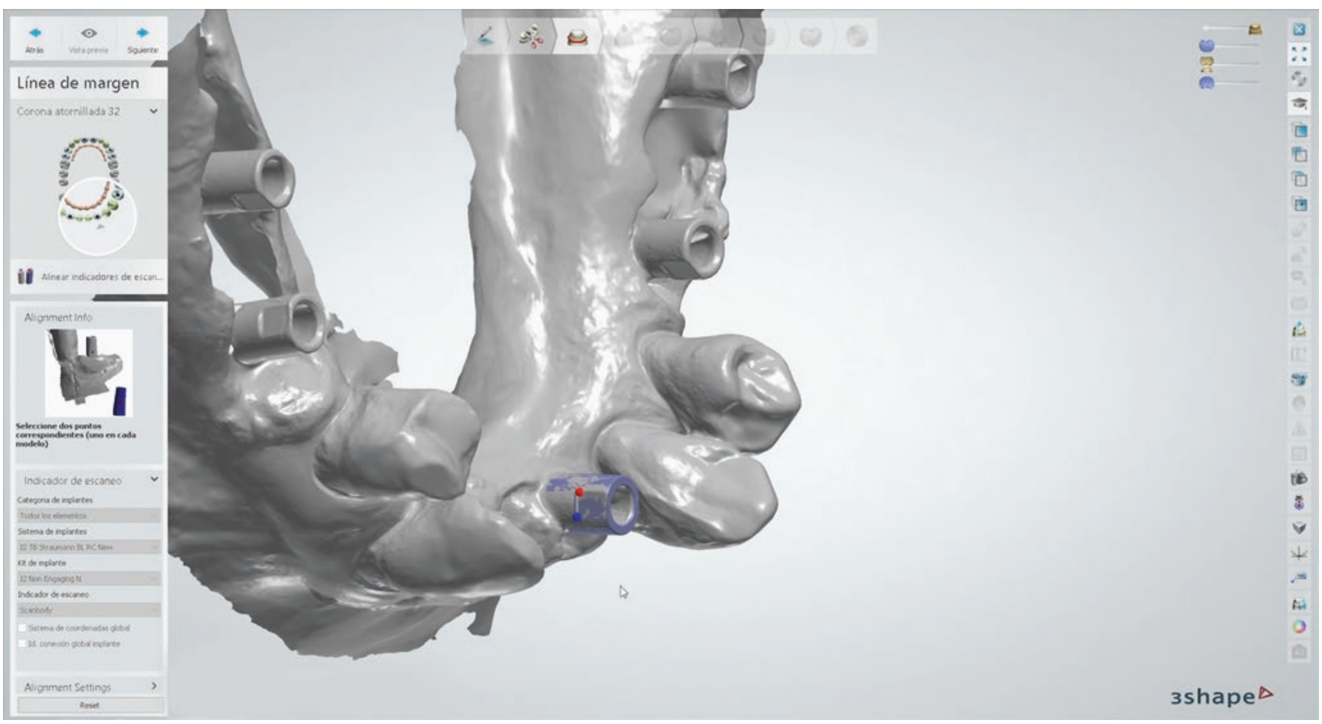


Fig. 18 Scan body best fit

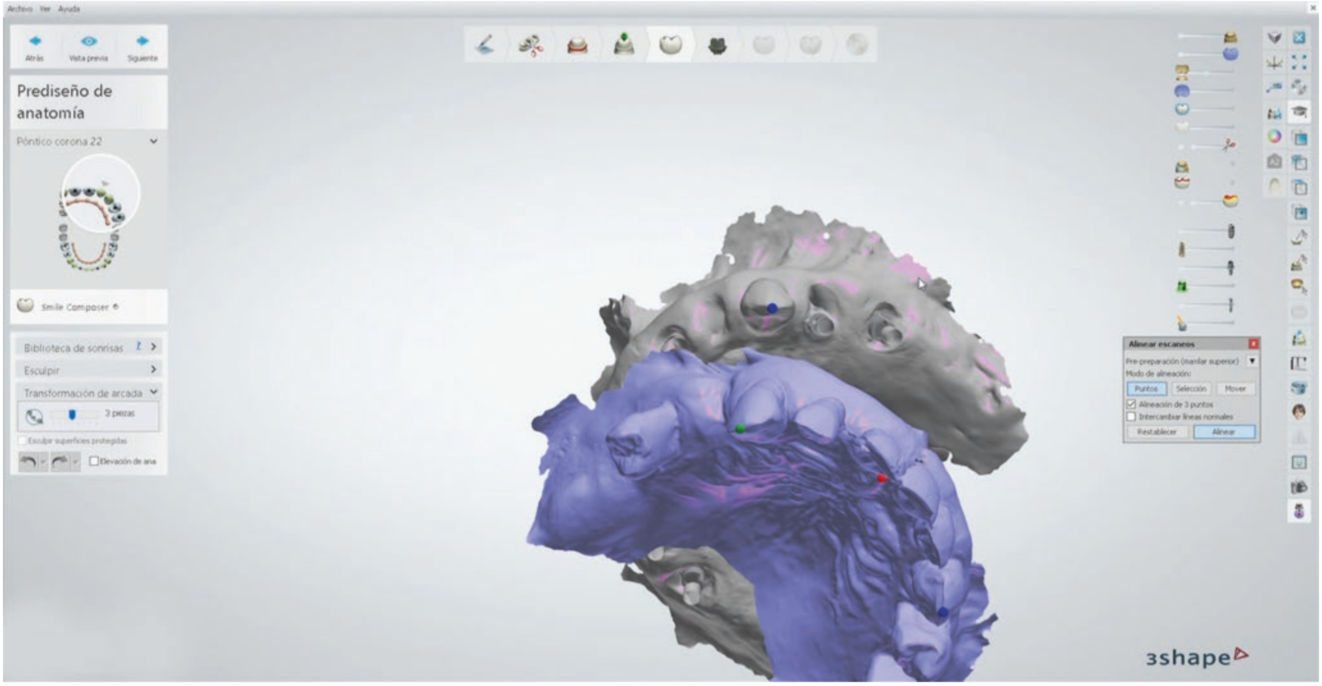


Fig. 19 Merging (best fit) of study model (consultation, preoperative) scan (blue) and implant file. Marking same points on both scans allow the software to import the study model scan as a pre-preparation on the final working file

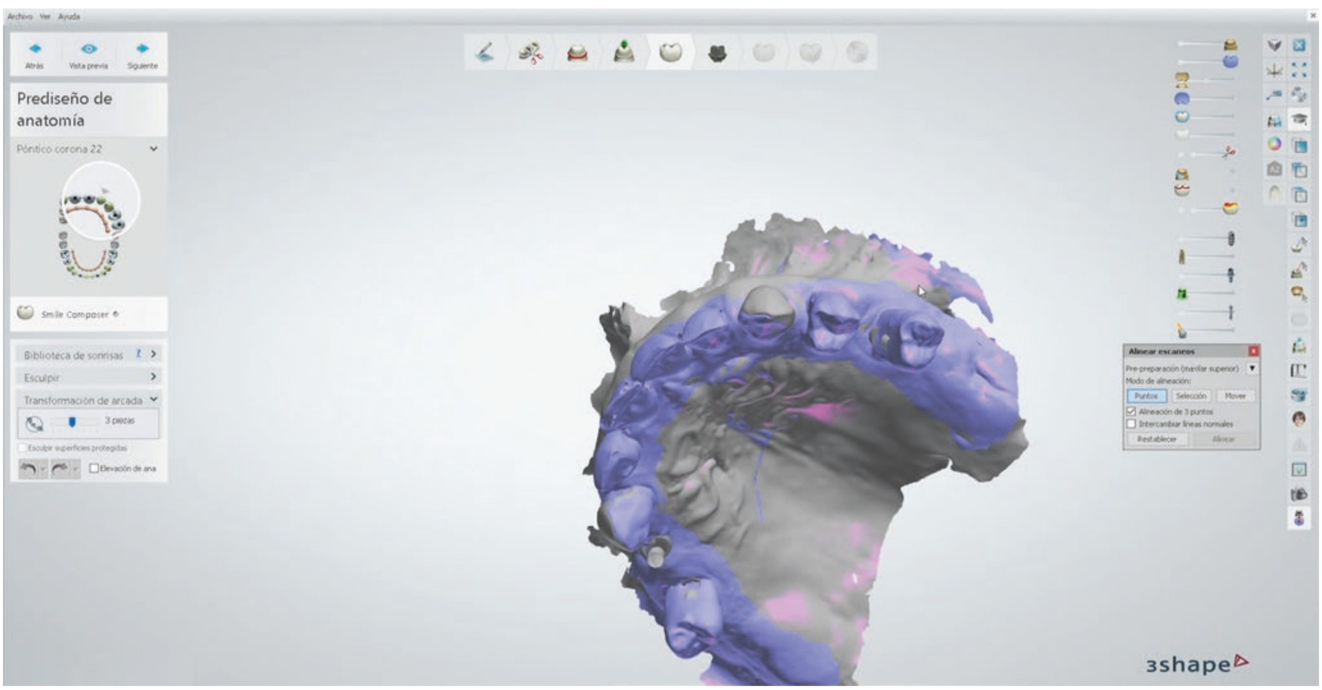


Fig. 20 Both files merged. Maxilla

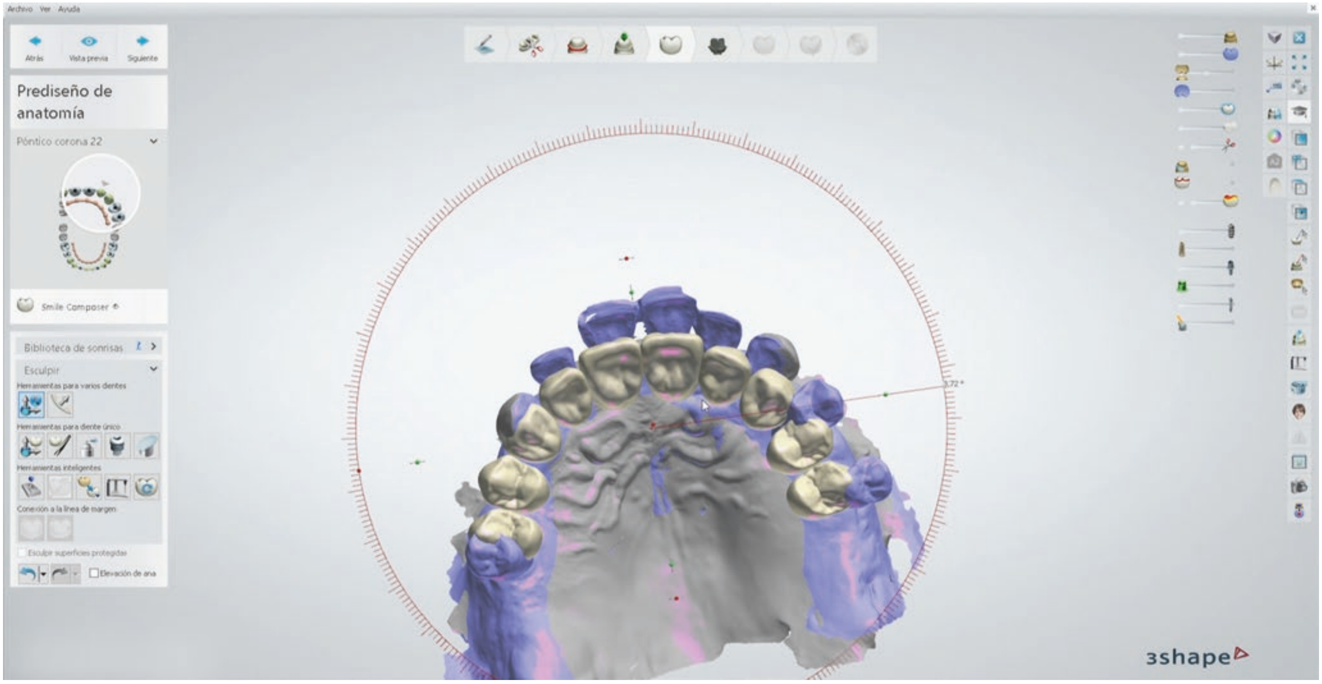


Fig. 21 Design process is simple; just copy the preoperative situation or modify the esthetics, keeping the functional information provided by the consultation scan

Fig. 22 Same procedure on the mandible

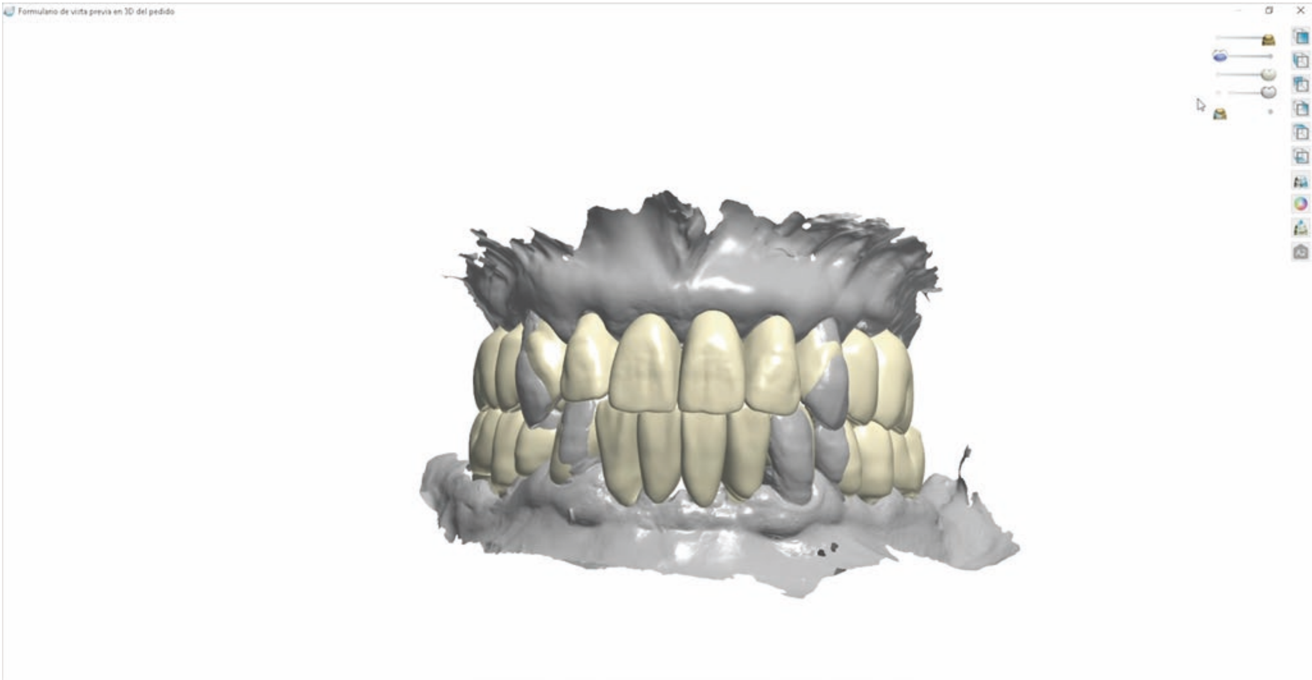


Fig. 23 Design is ready, keeping same functional information

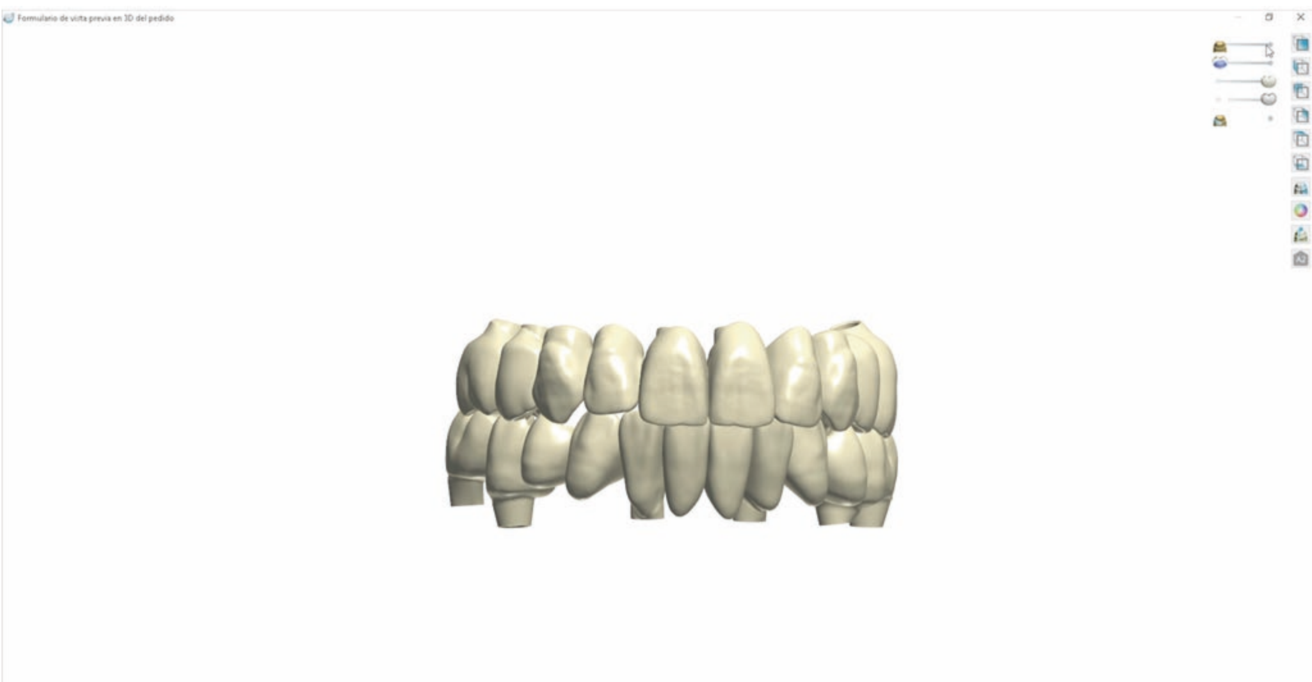


Fig. 24 Both temporary full arch bridges, ready to be milled

Fig. 25 Maxillary temporary full arch bridge placement. Frontal and occlusal view

Fig. 26 Maxillary temporary full arch bridge placement. Frontal and occlusal view

Fig. 27 Maxillary temporary full arch bridge placement. Frontal and occlusal view

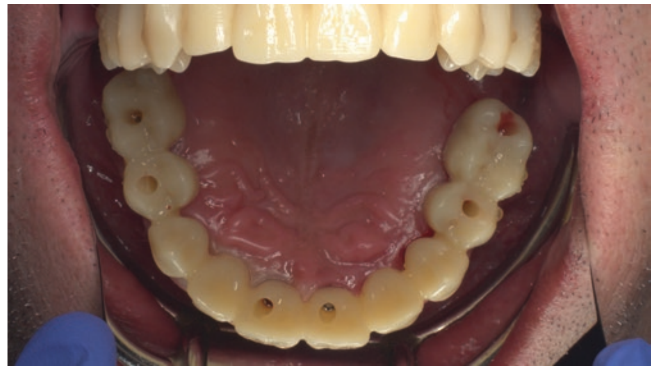


Fig. 28 Maxillary temporary full arch bridge placement. Frontal and occlusal view

Fig. 29 Mandible temporary full arch bridge placement. Frontal and occlusal view

Fig. 30 Mandible temporary full arch bridge placement. Frontal and occlusal view

Fig. 31 Final, same-day immediate result. Temporary full arch bridges in place

We then scan the treated maxilla with the scan bodies in place. It is important to correctly orientate the scan body on the implant to ensure that the part of it used to establish best fit is perfectly accessible to recording by the intraoral scanner.

The rest of the laboratory steps are similar to those of the standard technique (Figs. 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, and 50).

i2 Element and Protocol

In contrast to the above cases, in totally edentulous patients, and other situations as too mobile teeth, we have no reference elements allowing us to superimpose or overlap files from the intraoral scanner.

Fig. 32 Same-day smile

Fig. 34 Maxilla failing dentition. Preoperative situation

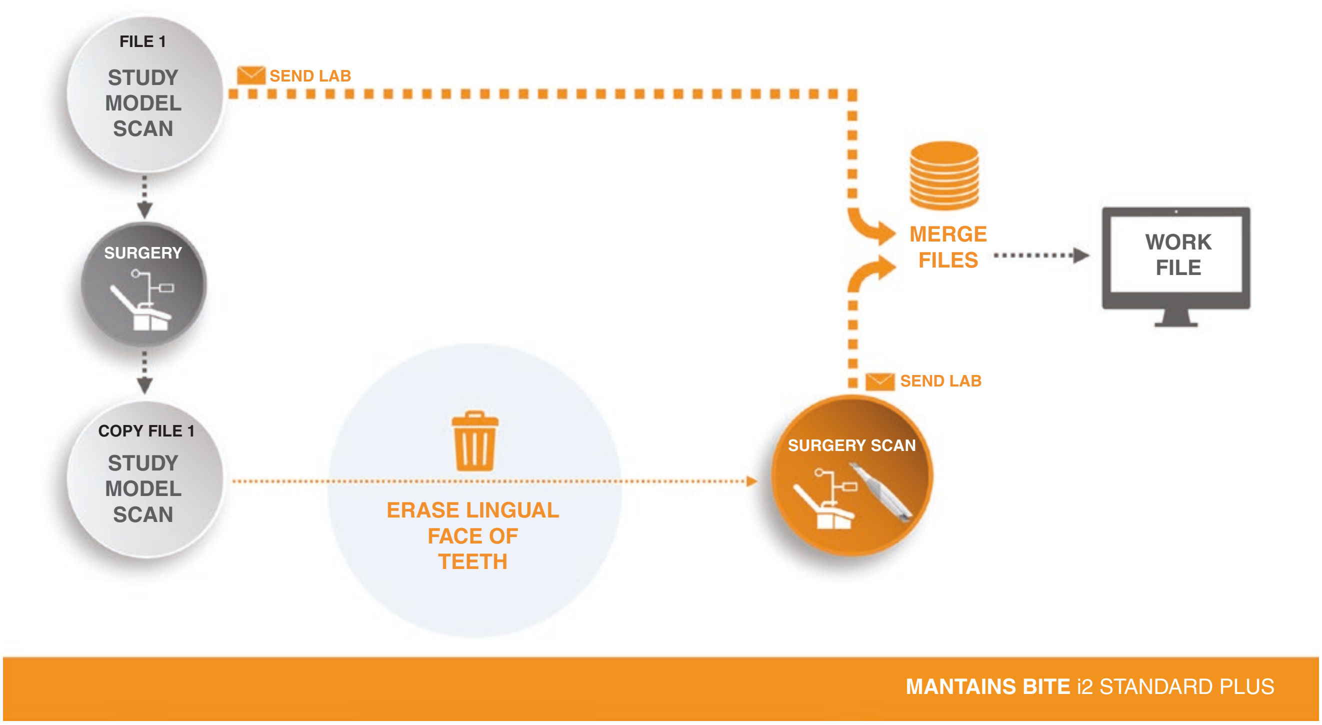


Fig. 33 I2 Standard Plus technique flowchart

Fig. 35 Preoperative X-ray

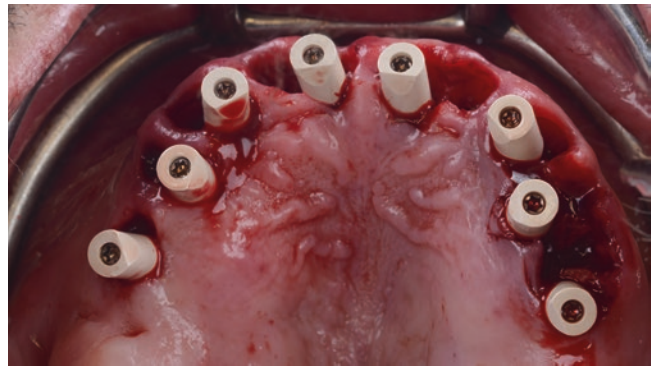


Fig. 37 Implants placed, scan bodies connected. Abutment level

Fig. 36 Preoperative. Study model scan

The i2 element was developed by us as a result of the need to create a reference element that can be placed in the maxilla destined for treatment according to the criterion of the operator in such totally edentulous individuals and also in many other clinical scenarios. Protected by IP rights, it is still under development, and it will be soon available as a complete solution: device, workflow, implants, and abutments. Contact us if you need more information.

The initial design of the i2 element is composed of a self-threading screw that is affixed to a geometrically significant structure. Placed strategically in the maxilla, it is used as a reference structure for aligning the different files generated

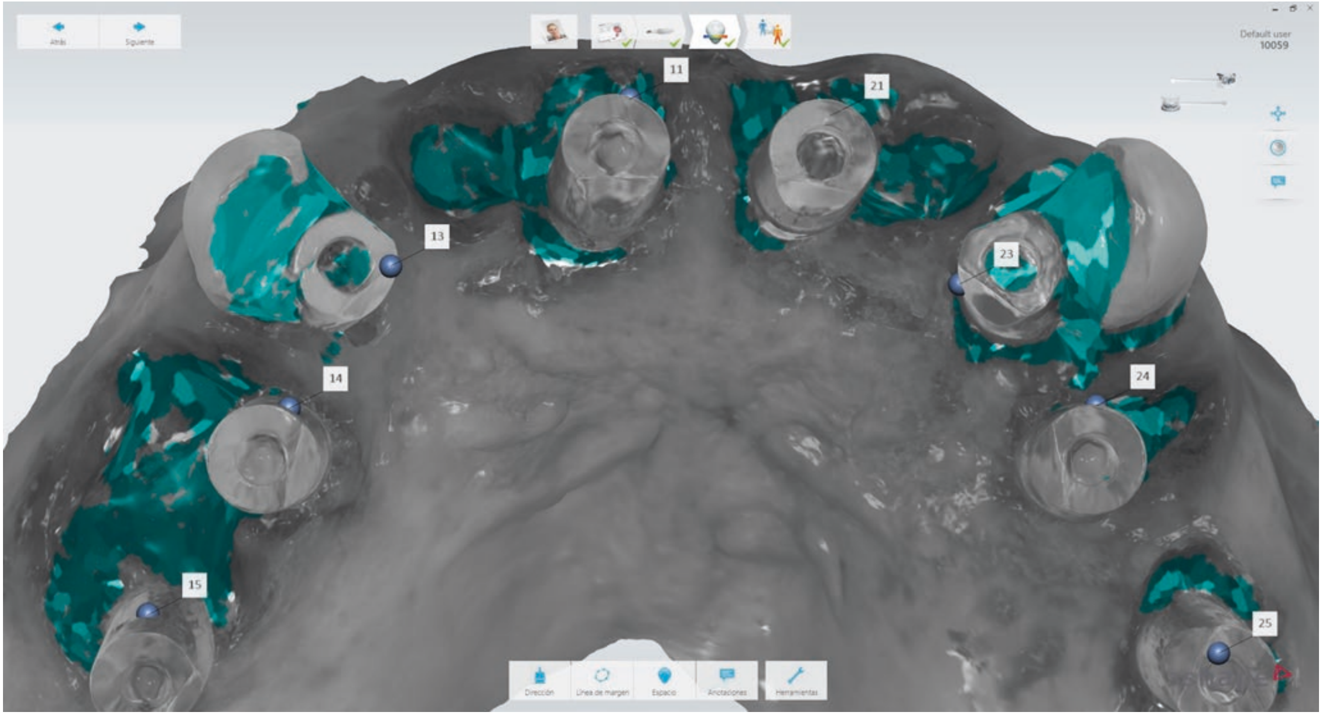


Fig. 38 Surgical scan. Note only the labial side of canines has not been erased. Working file is complete

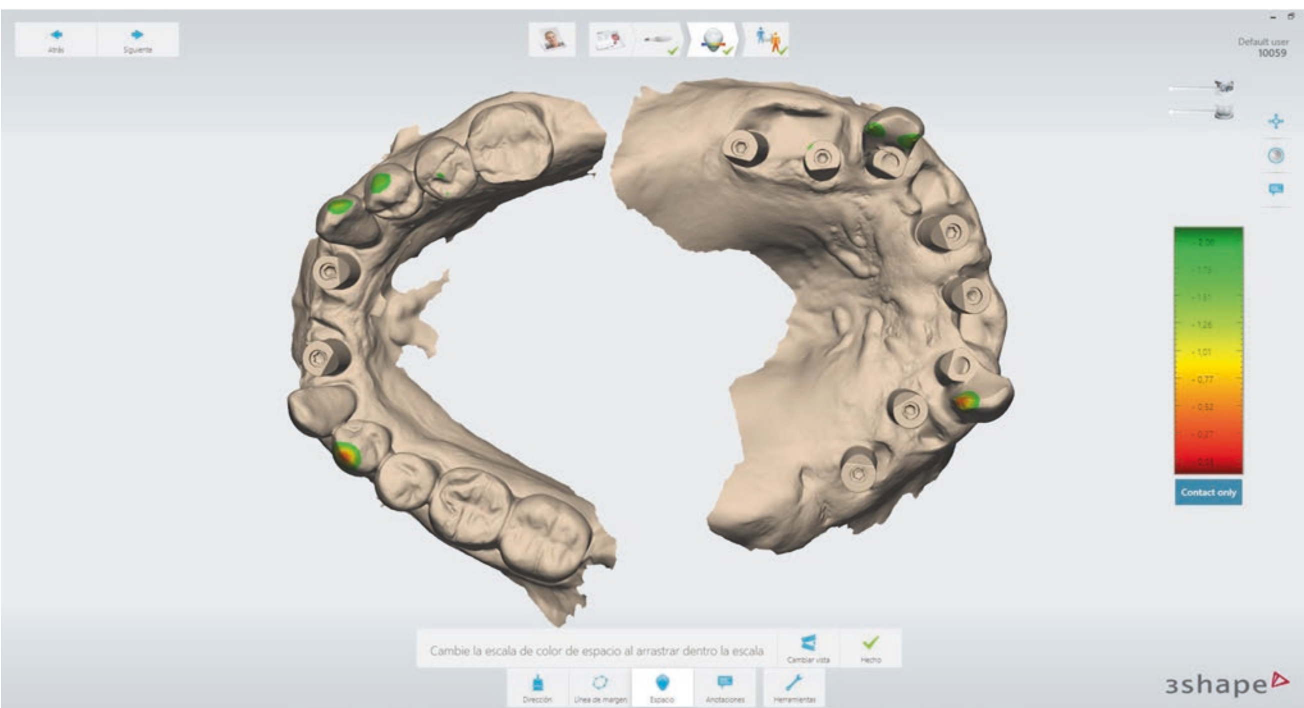


Fig. 39 Surgical scan bite contacts and space

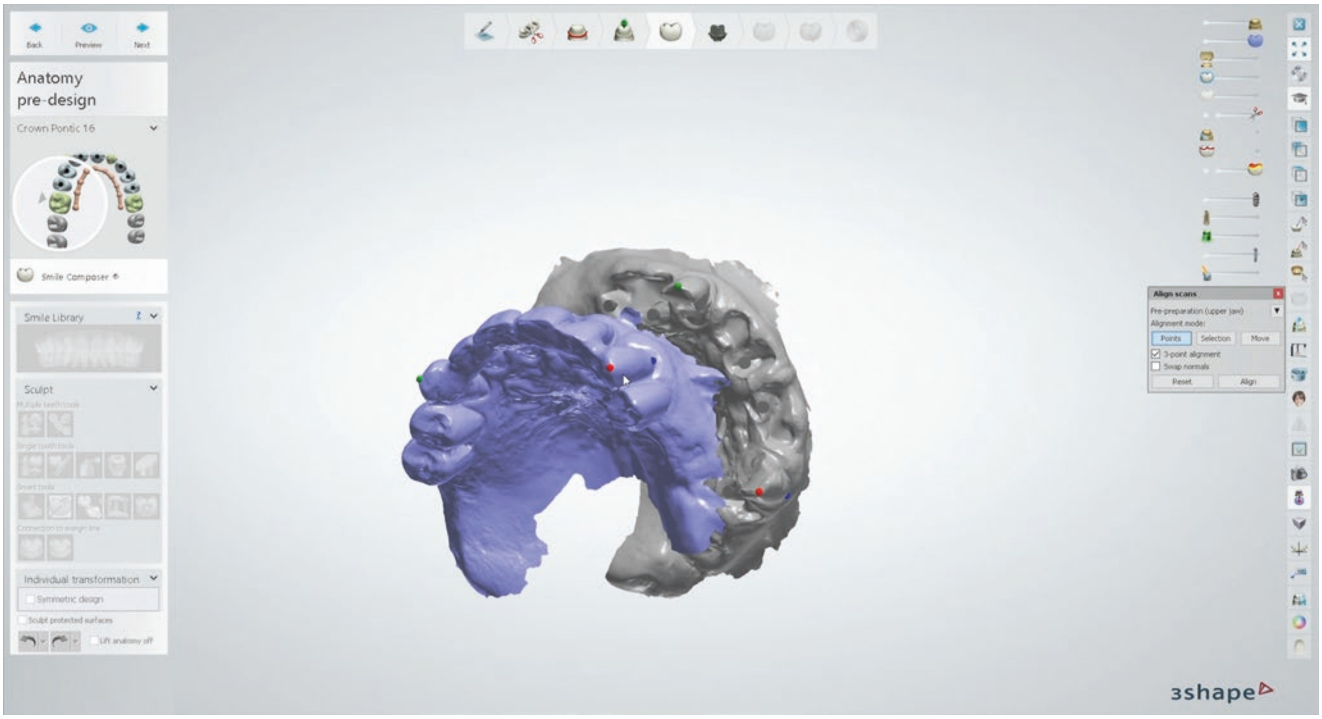


Fig. 40 Matching points seated on both, surgical scan and study model scan, to merge both files

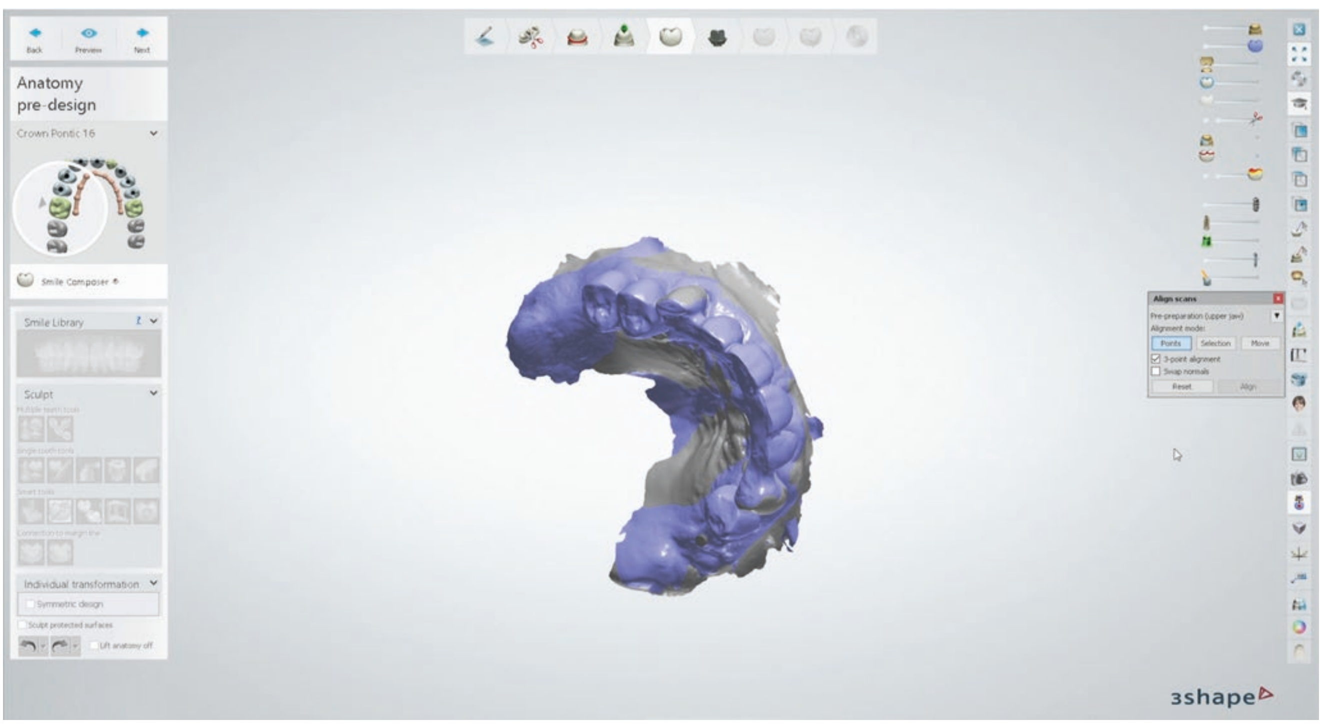


Fig. 41 Both files merged. Working file created

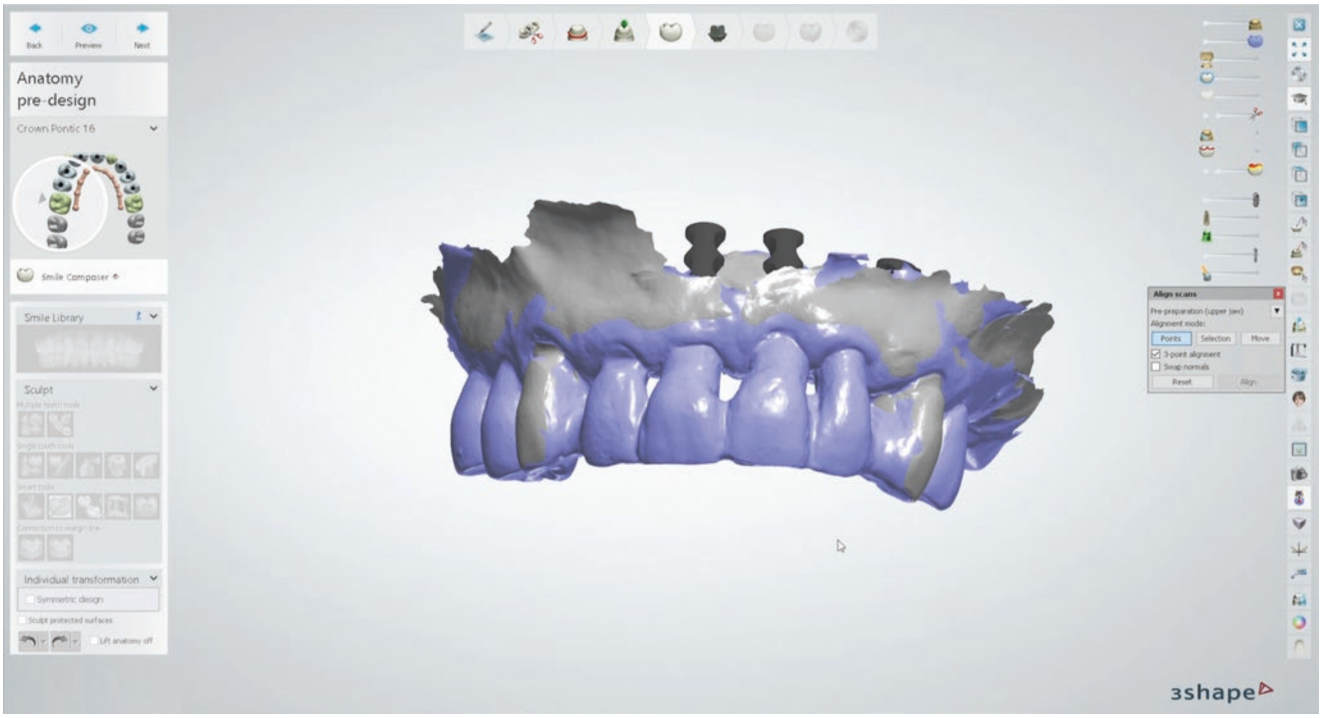


Fig. 42 Working file ready to design

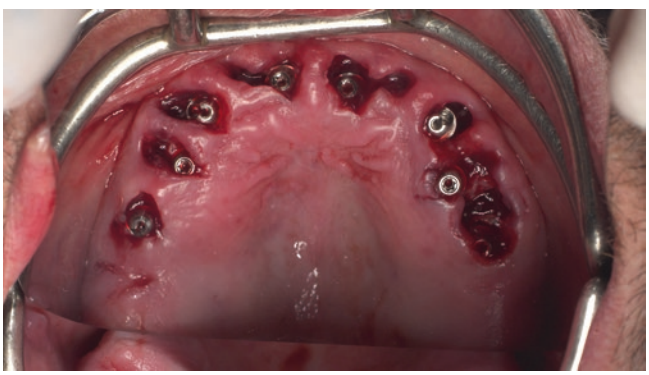


Fig. 43 Upper maxilla ready to place the temporary full arch bridge

Fig. 44 Temporary full arch bridge finished

Fig. 45 Occlusal view

Fig. 46 Temporary placed, same day

Fig. 47 Side view. Mirror

Fig. 48 Side view. Mirror

Fig. 49 Immediate same-day smile

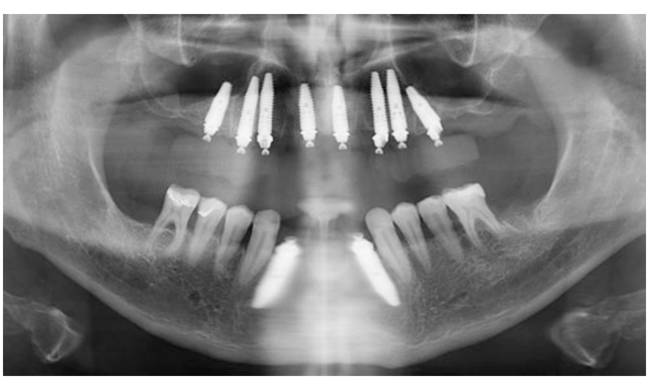


Fig. 50 Postoperative X-ray

by the intraoral scanner. In order for this to be possible, the i2 element must be present in the same spatial position in all the files pretended to be merged (Fig. 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, and 61).

The i2 element is therefore used as a reference structure to facilitate the alignment of different virtual files in different clinical situations in which we wish to copy the previous situation of the patient in the laboratory working files.

It is useful in the following applications:

- Copy of dental prostheses (partial, total, fixed, or removable)
- Copy in implantological revision surgery
- Copy of the provisional prosthesis, mock-ups or teeth try-in, to the working file in order to produce the definitive prosthesis
- Copy of previous clinical situations to transmit patient esthetics and function in cases of partial or total extractions
- Copy of mock-ups and waxing tooth morphology in cases or crowns, veneers, and bridges over natural teeth
- Generation of the GUi2 element in cases of guided surgeries and prostheses in totally edentulous patients
- Immediate full digital treatment of totally edentulous patients
- Guided surgery
- Ortho treatments

In sum, the i2 element present in several digital files produced by intraoral scanning of one same patient (and assuming the i2 element is located in the same spatial position in all the files) will allow the laboratory technician, with the help of CAD software, to superimpose the files corresponding to that patient.

The i2 element therefore facilitates adequate data transfer to the laboratory technician, shortening the overall treatment time, with increased precision and creating new flows both in CAD design and at clinical level that will directly benefit our patients. In this regard, the entire CAD-CAM flow is more precise and more exact in relation to both the functional and esthetic parameters.

As a practical example of treatment using the i2 element, in the case of a totally edentulous patient, with a complete prosthesis, we can start from the patient prosthesis as copy element and subsequently introduce the esthetic and functional changes required in the CAD design phase or alternatively produce a tooth try-in before surgery, with the modifications we desire. In other words, we can copy either the complete prosthesis of the patient or a teeth try-in.

The i2 element workflow comprises the following:

1. Placement of the i2 Elements:

   Based on the patient explorations made, we identify the possible locations of the implants that will support the immediate prosthesis. We also select the possible loca-

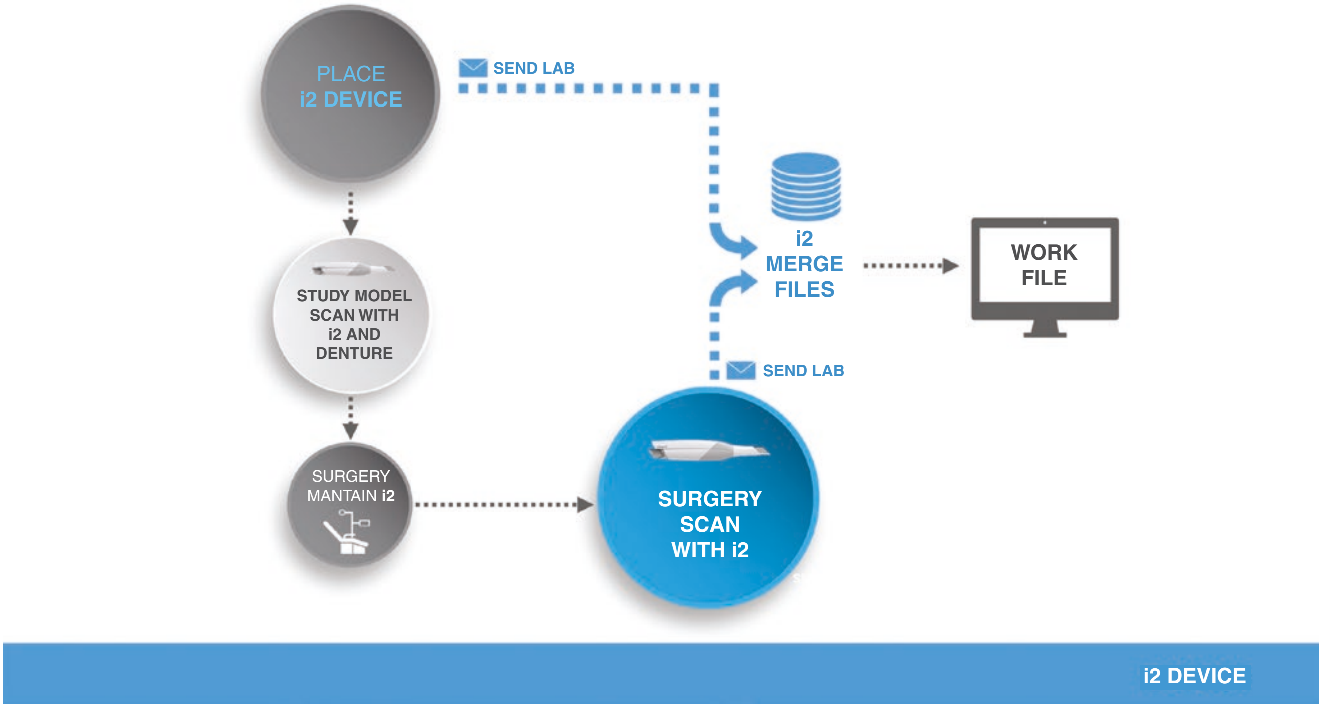


Fig. 51 i2 device flowchart

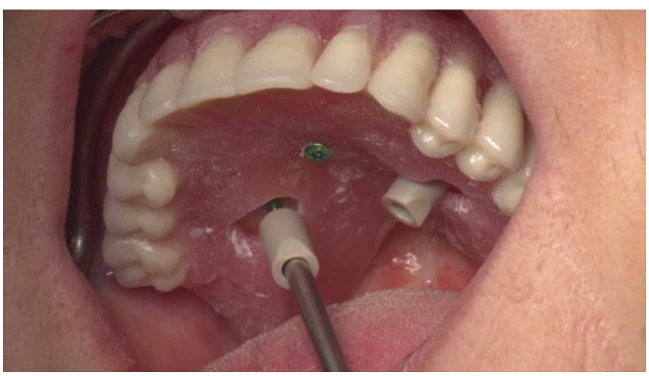


Fig. 52 Placement of two i2 devices on a full edentulous patient. Note treatment starts from a new teeth try-in

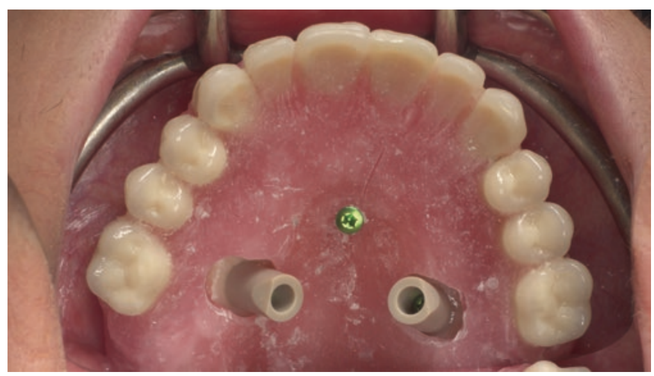


Fig. 53 Occlusal view. An osteosynthesis screw is also securing the try-in to the jaw to be treated

tions of the i2 elements. The latter must not compromise either the locations where the implants will be placed or the course of surgery and must be easily accessible to reading by the intraoral scanner.

Thanks to the self-threading capacity of the i2 element, it can be placed mechanically without gingival incision using the handpiece. An insertion speed of 25–45 rpm and torque of 45 Ncm are advised. If necessary, definitive tightening can be done manually until the flat portion (the part used for alignment) of the i2 element is conveniently oriented and completely firm and immobile. It is crucial to ensure that the i2 element cannot move in any way.

2. We then place the complete prosthesis in the mouth, adjusting it if necessary in order to prevent it from impacting against the placed i2 elements.
3. A first intraoral scan is made, recording the maxilla to be treated, antagonist, and bite. The file thus generated will contain the complete prosthesis (or teeth try-in) with the i2 elements, the antagonist maxilla, and bite (file 1).
4. We remove the complete prosthesis, start surgery, and place the implants without removing the i2 elements. The scan bodies are finally placed on the implants.
5. A copy of the first scan (file 1) is made, eliminating the scan of the maxilla undergoing treatment. We then obtain the definitive intraoral scan of the maxilla being treated.

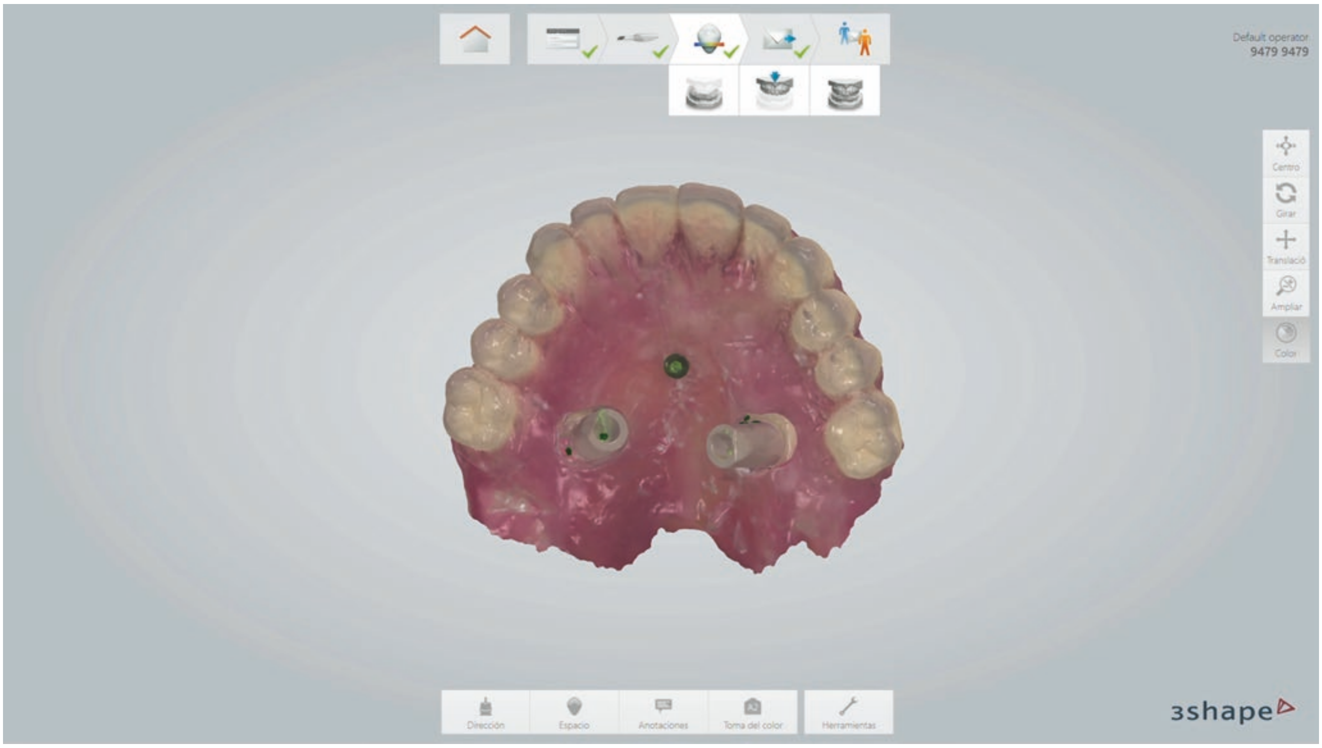


Fig. 54 File 1 from the intraoral scan, showing the i2 and the try-in

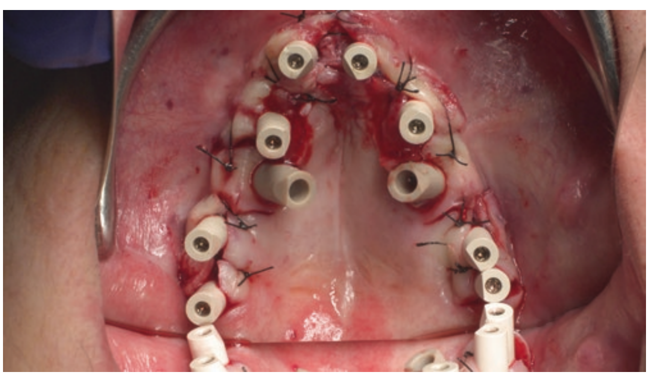


Fig. 55 Intraoperative occlusal view. Implants placed. Scan bodies connected. i2 devices are in the same position as in File 1

This file will contain the scan bodies of the implants and the i2 elements (file 2).

6. Both files (files 1 and 2) are sent to the dental laboratory. After confirming that they have been correctly received, we remove the i2 elements from the mouth of the patient.
7. The laboratory uses file 2 to create the working model, performing the best fit of the physical scan bodies of the implants with respect to the virtual scan bodies. File 1 is imported as pre-preparation over this model. The i2 elements present in the same positions in the two files (1 and 2) are used to align both files. Matching zones and alignment points of the i2 elements allow the two files to be superimposed.

This workflow allow us to overlap the information contained in both files, for example, the teeth try-in or complete prosthesis of the patient with respect to the surgery scan. Thanks to this, designing and producing the immediate fixed provisional prosthesis is a very simple procedure.

The so designed fixed provisional prosthesis contains all the information of the complete prosthesis of the patient or of the teeth try-in.

It is important to mention that months later, once we have reached the definitive temporary prosthesis (with the correct final functional and esthetic parameters), the i2 elements will be used in the same way to copy this information in the final intraoral implant scan for designing the definitive prosthesis.

The i2 elements are placed in the maxilla with the definitive provisional prostheses. We then perform the intraoral

Fig. 56 Postoperative intraoral scan (File 2) containing all the elements showed in Fig. 107

Fig. 57 Marking alignment points on both i2 to merge Files 1 and 2

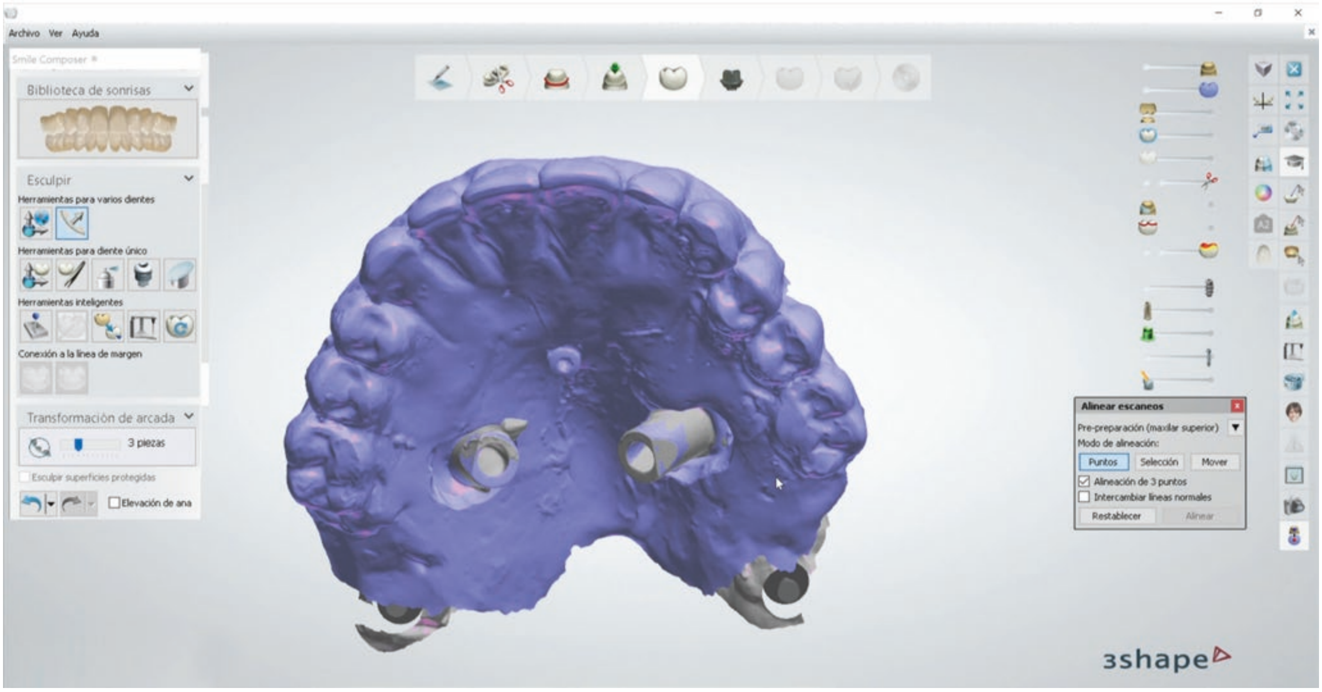


Fig. 58 Both files merged

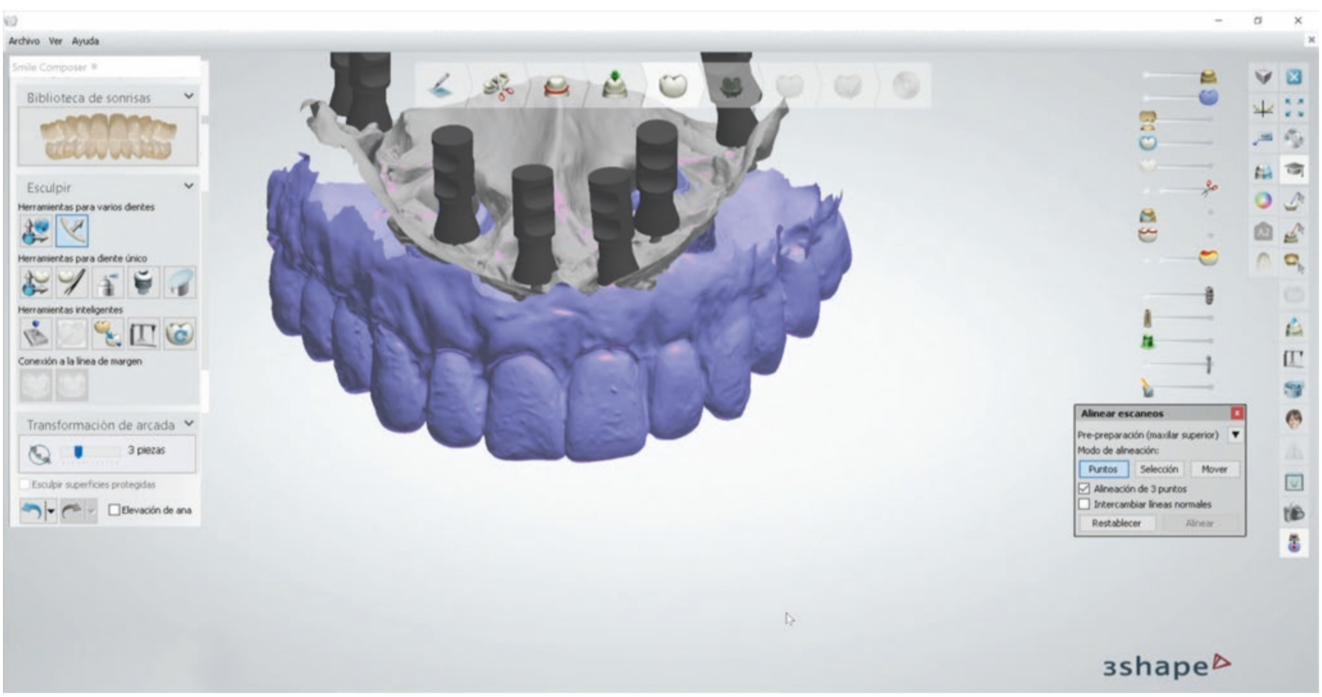


Fig. 59 Both files merged with implant position

Fig. 60 Finishing the digital design, the temporary full arch, same day has been milled in Telio CAD and characterized and now is ready to be placed on our patient

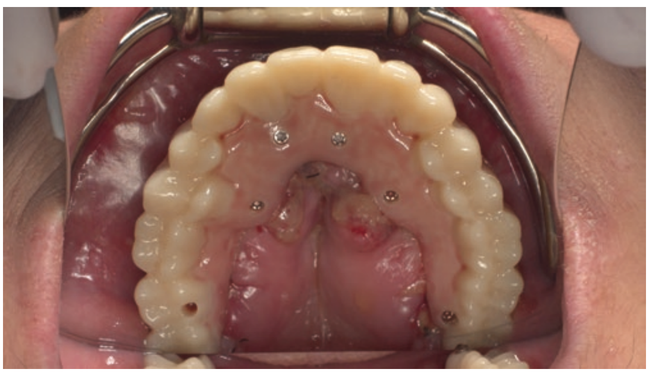


Fig. 61 After placement, occlusal view. Final same-day result

scan of the maxilla with the provisional prosthesis and the i2 elements. The provisional prosthesis is removed, leaving the i2 elements in the same positions as before, we place the scan bodies on all the implants, and a new intraoral scan is made containing the scan bodies and the i2 elements. Thanks to these elements, the laboratory will superimpose the two files and design the definitive prosthesis in a simple manner, adhering to the information provided by the provisional prosthesis.

Case presentation: A 46-year-old patient with no medical impairment, presented with a terminal dentition in the upper maxilla and without any prostheses. In the lower maxilla, he wears an old complete denture. The treatment plan is to provide the patient with both fixed temporaries.

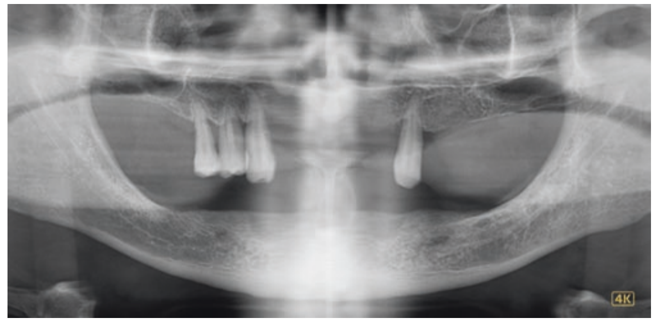


Fig. 62 Preoperative X-ray

Fig. 63 i2 device placement

Fig. 64 i2 device in place, ready to start study model scan (file 1)

Because of the presence of the old denture in the jaw, it was decided to start with the mandible, using the i2 device protocol. Upper maxilla will be treated with the i2 mixed protocol (Figs. 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, and 96).

Fig. 65 Different views of this first IO scan (file 1)

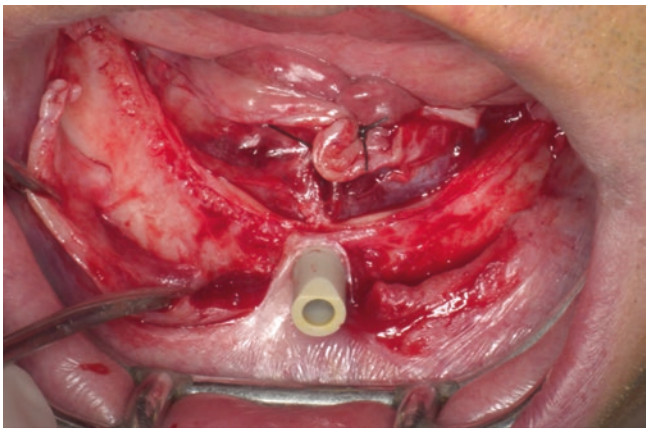


Fig. 66 Flaps opened to locate both mental nerves. I2 device in the same position, untouched

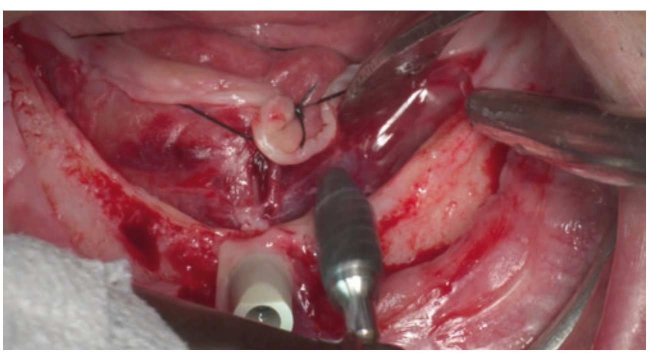


Fig. 67 Flattening the ridge

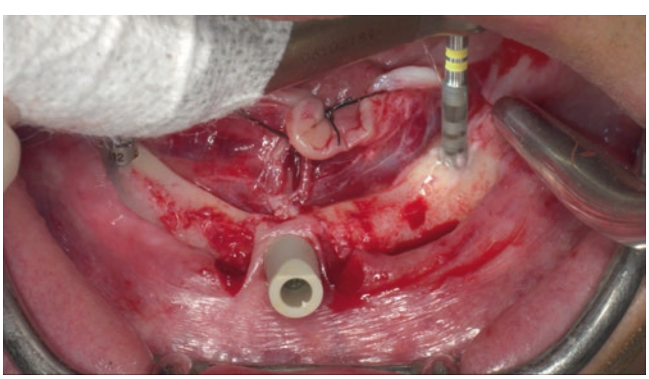


Fig. 68 Implant bed preparation starts for the most two distal implants planned, assessing anatomy and bone density and angulation

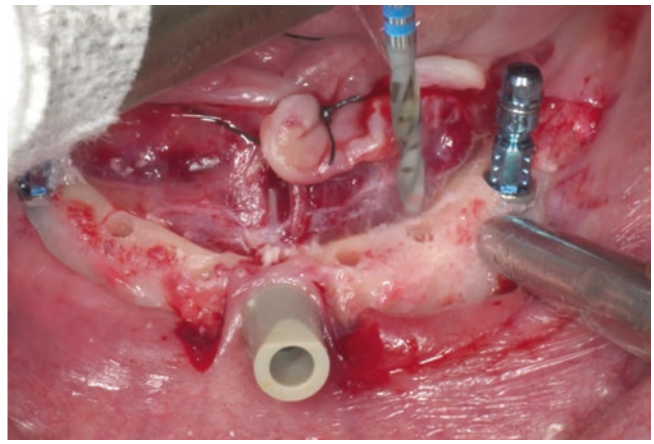


Fig. 69 After those implants had been placed, implant bed for the rest of the implants is prepared

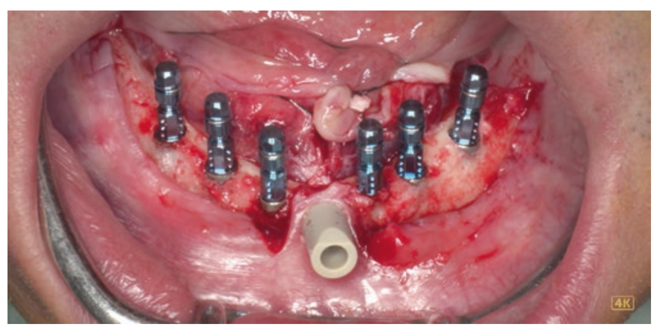


Fig. 70 Six implants placed. It is important to control the angulation between the implants

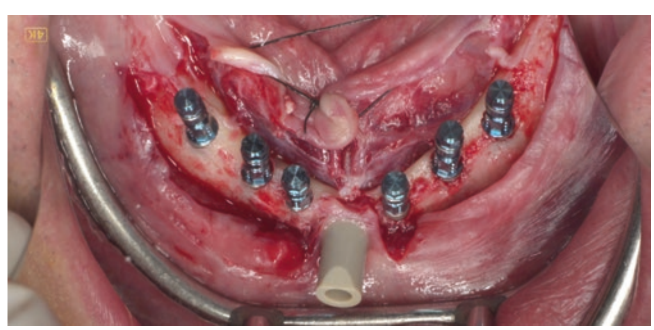


Fig. 71 Occlusal view

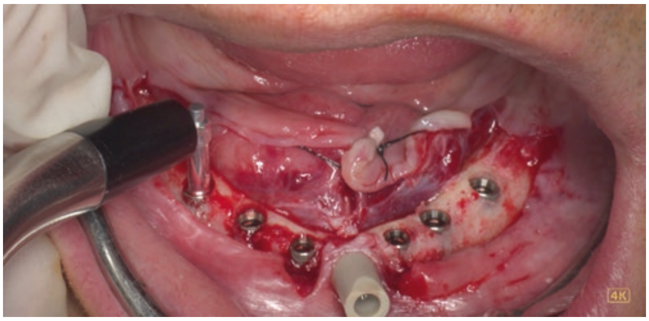


Fig. 72 ISQ at implant level is recorded

Fig. 73 High ISQ on all the implants placed

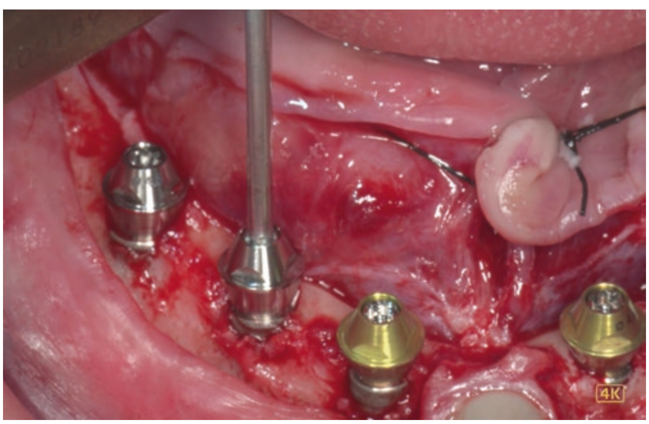


Fig. 74 SRA abutments are placed on the implants

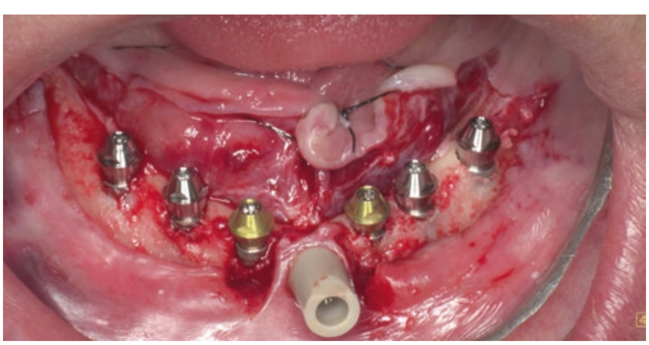


Fig. 75 Anterior view with the SRA abutments placed

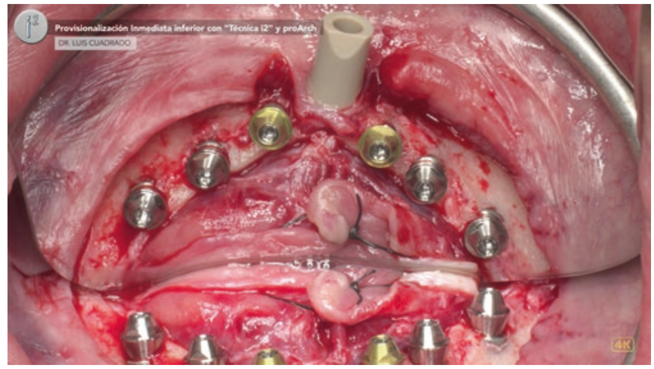


Fig. 76 Occlusal view

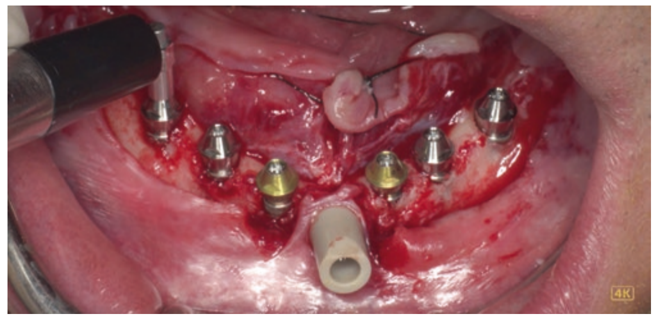


Fig. 77 ISQ to SRA level is recorded

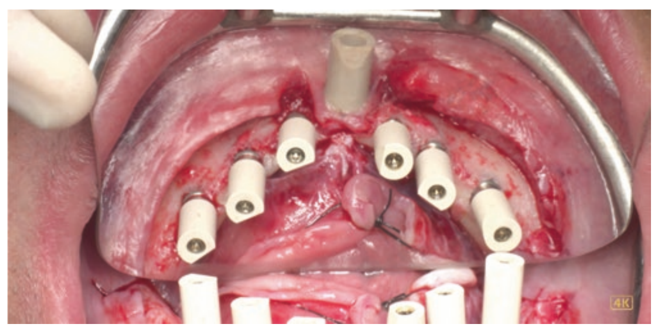


Fig. 78 Scan bodies connected to the SRA abutments prior to closing the flaps

Fig. 79 Use of suspensory sutures to avoid movement of the flaps. With a round drill, a hole is performed in the bone

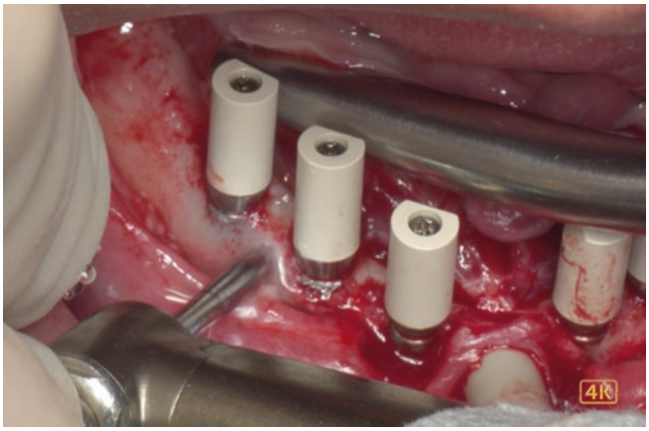


Fig. 80 Contralateral side

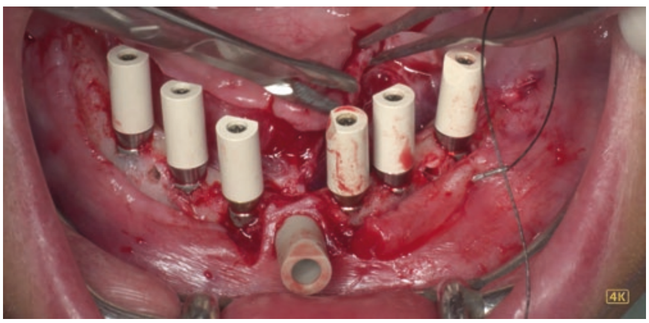


Fig. 81 The suture is performed from the buccal to the lingual flap, through the hole on the bone

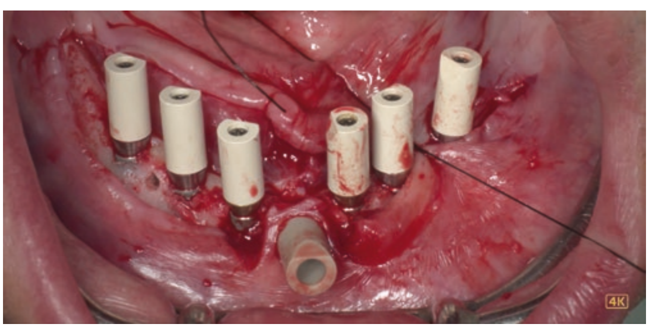


Fig. 82 Tightening the stich

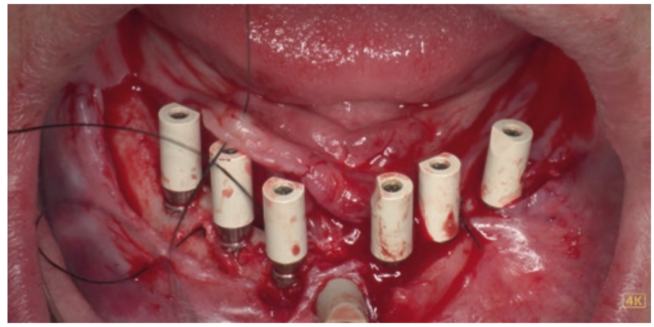


Fig. 83 Same procedure contralateral side

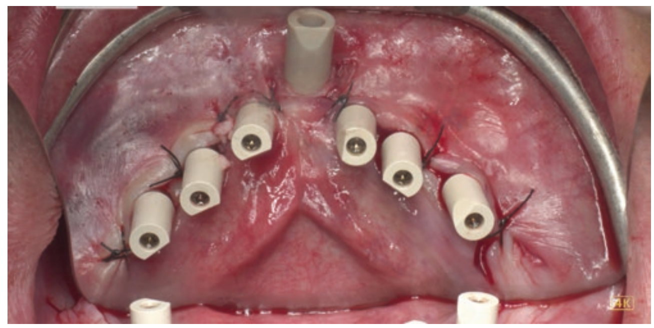


Fig. 84 Final immediate result. Now the floor of the mouth is fixed to the bone. Everything is ready to perform the final intraoral scan

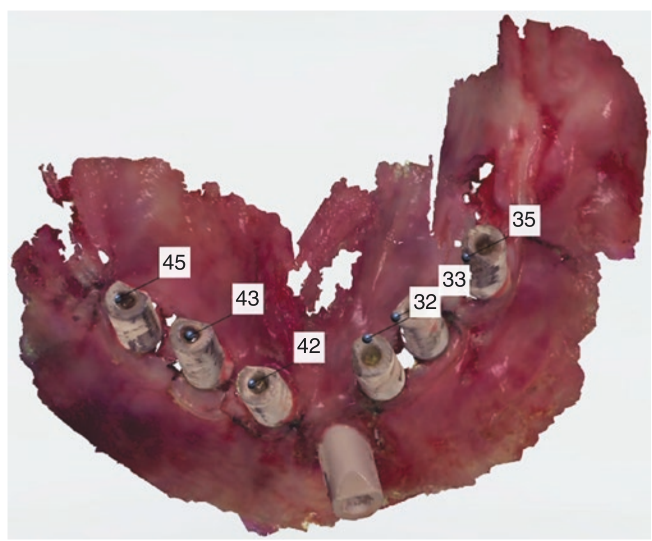


Fig. 85 Implant intraoral scan, comprising also the i2 device (file 2)

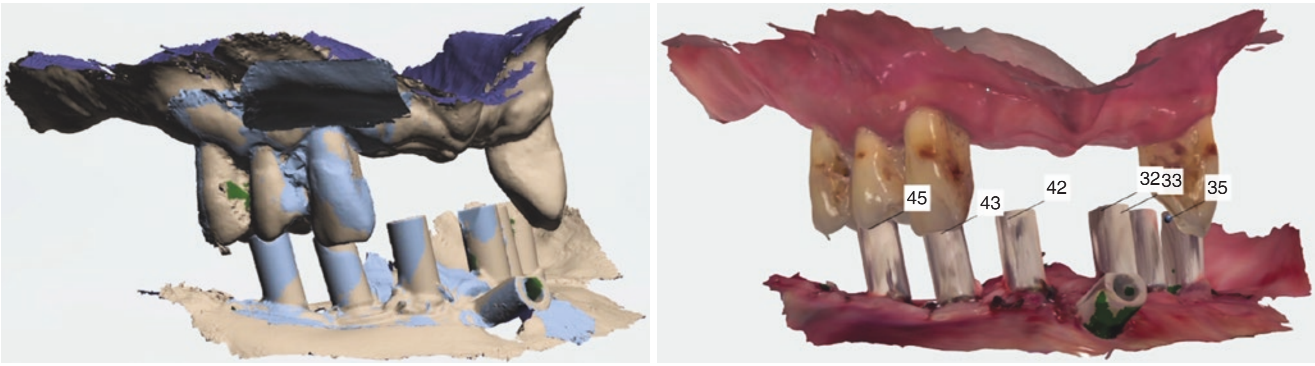


Fig. 86 File 2 scan bite

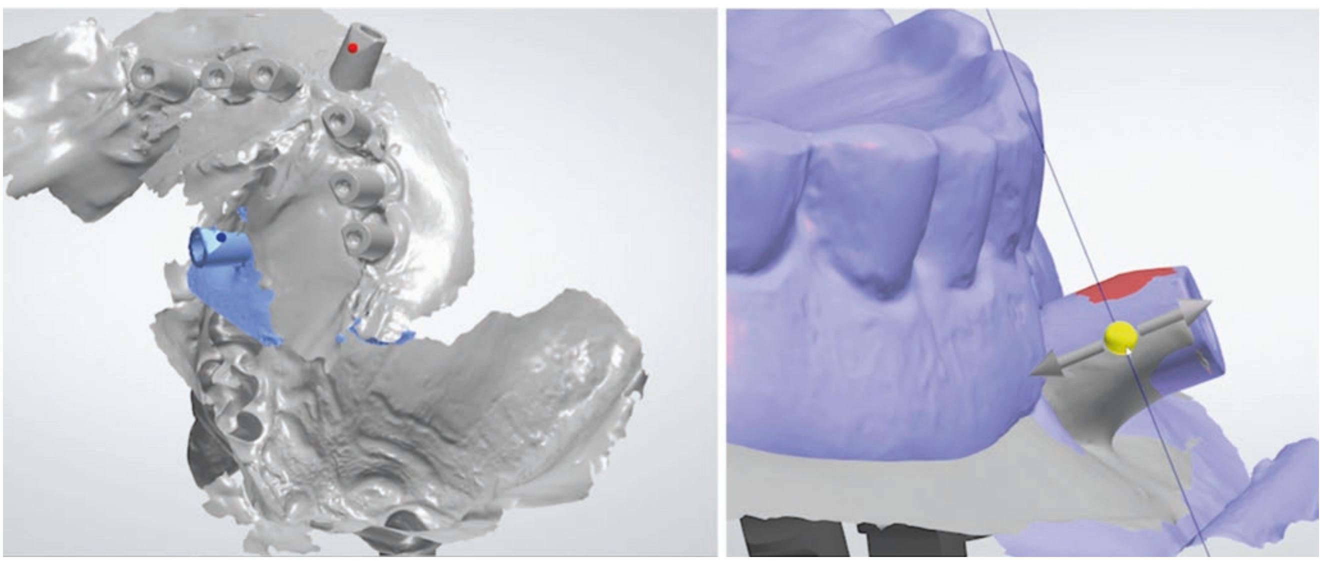
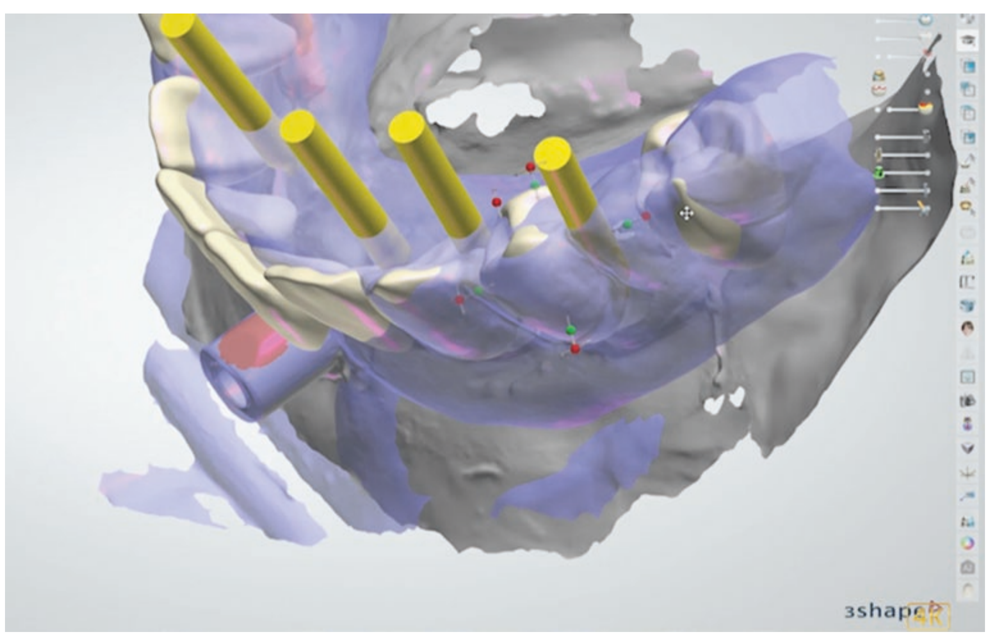


Fig. 87 Merging both files 1 and 2

Fig. 88 The lab works on a single file, where file 1 is a pre-preparation, to be copied (or modified) in the temporary full arch fix prostheses



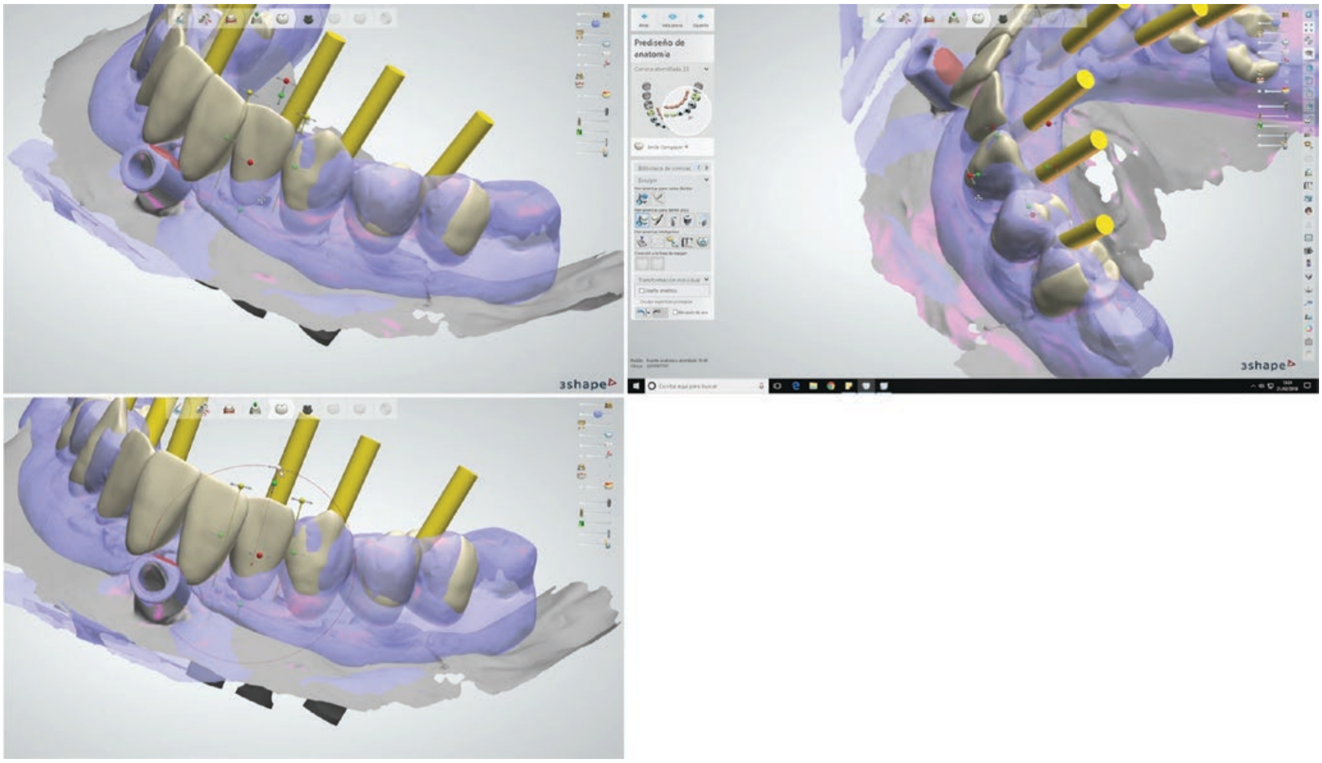
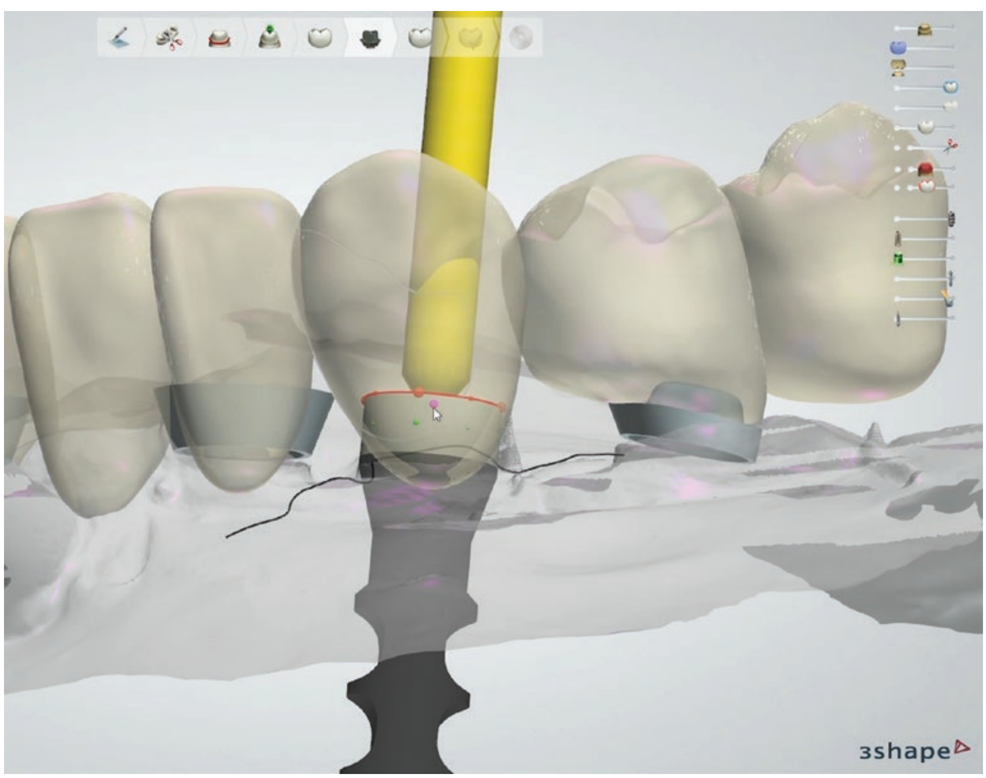


Fig. 89 Thanks to the i2 device, the dental technician has all the information coming from the old complete denture of the patient

Fig. 90 An important step is to design the emergence profile



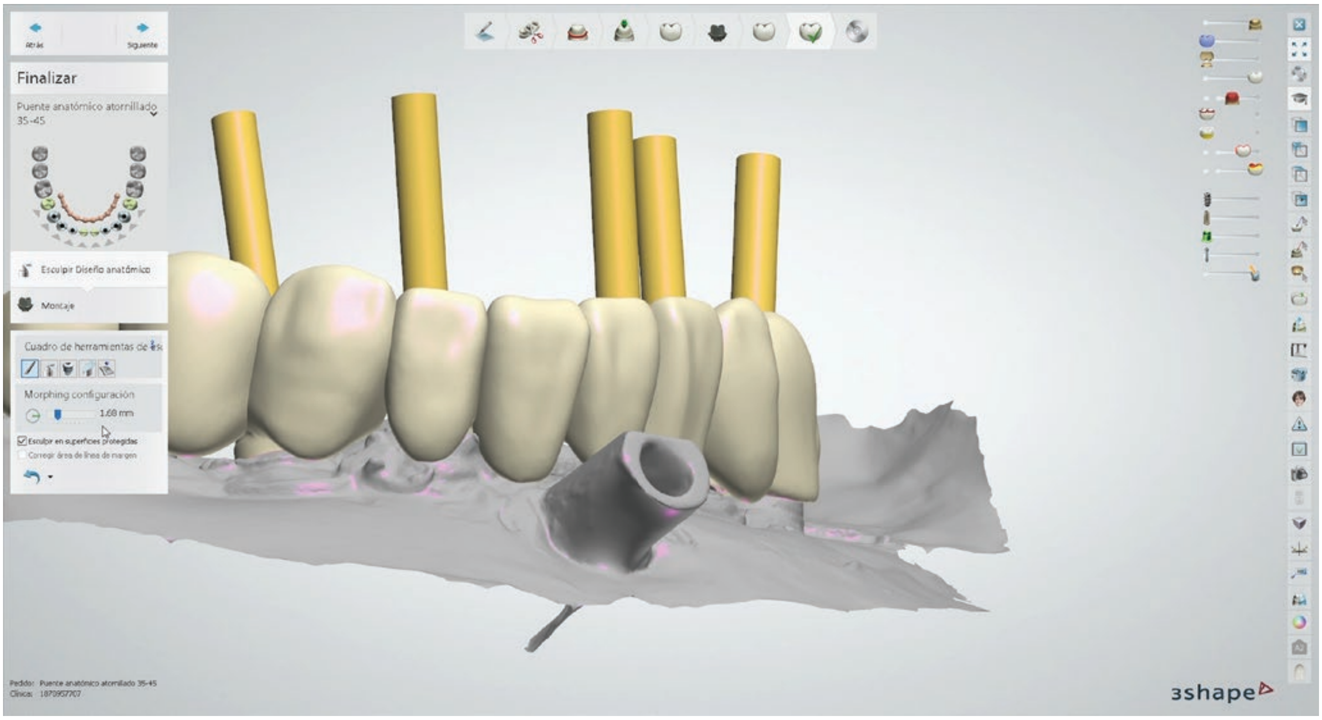


Fig. 91 On the virtual model with the i2, the temporary is designed

Fig. 92 Once milled in Telio CAD, and processed, the temporary is ready to be placed on the implants

Fig. 93 Torque control with the handpiece

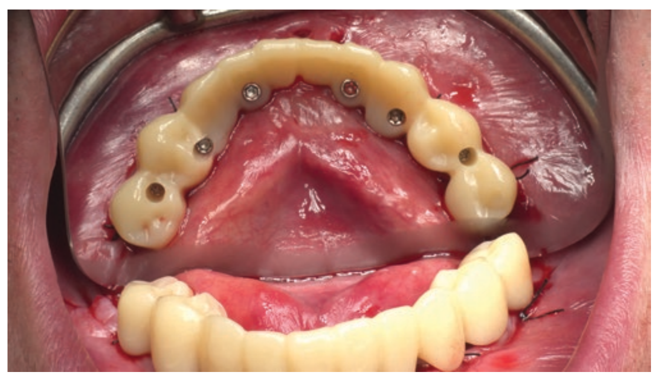


Fig. 94 Fixed full arch placed, same day

Fig. 95 Frontal view. Immediate result

Fig. 96 Postoperative X-ray

The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: Guided Treatment Protocols

Luis Cuadrado, Cristina Canals Salinas, Cristina Cuadrado Canals, Andrea Sánchez Becerra, and Luis Cuadrado Canals

Take-Home Message
The possibilities of rehabilitating edentulous patients have different approaches. It is possible to offer a same-day immediate loading by means of guided or non-guided surgery. Guided surgery has become the most common workflow for this type of rehabilitation; however, we have involved different elements and tools in order to make this protocol easier meeting all the functional and esthetic demands of the patient and which can guide us toward the definitive prosthesis successfully.

Classical Double CT Technique

The guided surgical treatment of totally edentulous patients traditionally has been based on software using the double computed tomography (CT) technique. After placing radiopaque elements on the complete prosthesis, a CT scan is made with the complete prosthesis in the mouth of the patient, generating a first DICOM file. A second CT scan is then made of the prosthesis to generate a second DICOM file. Using the guided surgery software, and thanks to the presence of these radiopaque markers, both DICOM files are superimposed, and guided planning can be made. In our opinion, however, since the surgical guide is based on the DICOM file, placement of the implants and adjustment of the guided prosthesis (also fabricated from these DICOM files) might not be precise—thus making intraoperative modifications necessary in order to secure an adequate fit of the temporary prostheses.

Case Presentation
A 72-year-old patient was referred for implant treatment after a bimaxillary implant failure. No medical contraindications were found, and a staged implant treatment with guided surgery, starting for the upper maxilla, was offered to the patient.

A double CT technique was considered in this case, due to the perfect fit of his complete temporary denture and to avoid extra costs. Radiopaque markers were placed on the denture, and a CT of the patient wearing the denture with markers and another CT of the complete denture alone were taken (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23).

At present, the great accuracy of guided surgery software is due in our opinion to the fact that the surgical guide can be designed on an STL file from the intraoral scan of the patient.

The GUi2 element arises from the need to use the intraoral scan in designing the surgical guide (and the guided provisional prosthesis) in the totally edentulous patient.

GUI2 Element and Protocol

The initial objective of treatment in patients of this kind is likewise to produce a "model" fixed prosthesis meeting all the functional and esthetic demands of the patient and which can guide us toward the definitive prosthesis. Our protocol involves using the advantages of guided surgery in such patients but radically modifying the workflows in an environment we refer to as GUi2, which makes use of an element with the same name (GUi2).

This workflow gives enormous precision to guided surgery of the totally edentulous patient, to the point where the objective of treatment is not only guided implant placement but also the direct connection, without indirect modifications, of the immediate and fixed provisional prosthesis designed and created before surgery, thanks to our guided planning. In fact, this approach creates a new type of guided implant treatment we named guided prosthetics.

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M. Peñarrocha-Diago et al. (eds.), *Atlas of Immediate Dental Implant Loading*, https://doi.org/10.1007/978-3-030-05546-2_17

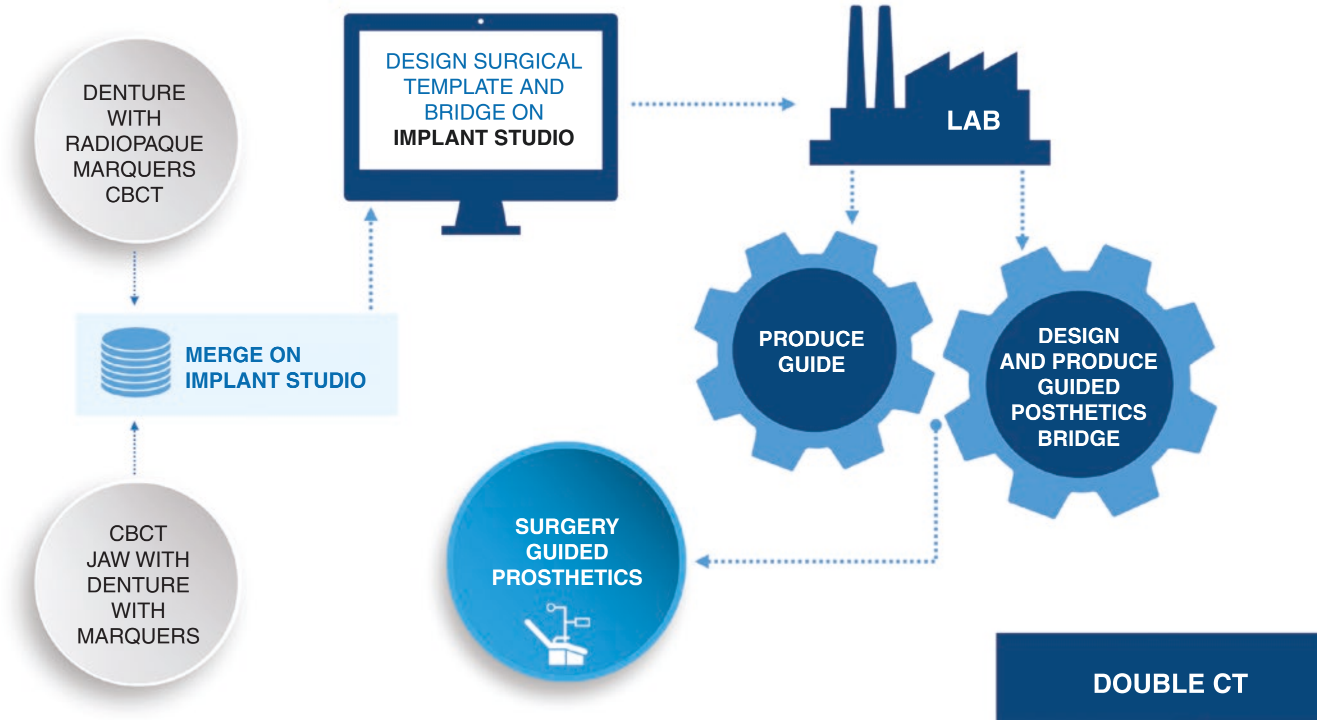

Fig. 1 Double CT flowchart

Fig. 2 Preoperative, frontal view of the patient

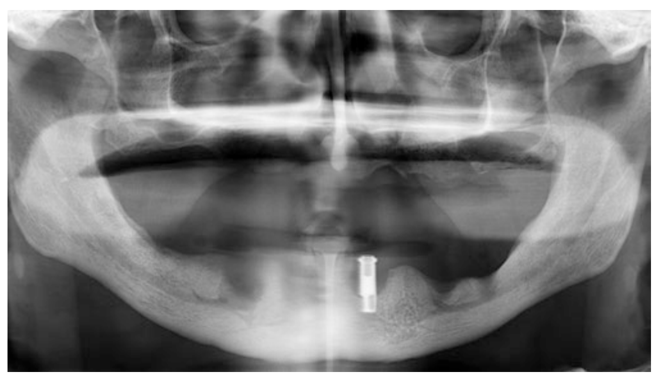

Fig. 3 Preoperative OPG of the patient

Used under the concept and workflow of guided surgery and prosthesis, the GUi2 element is a monoblock, radiopaque acrylic structure composed of connectors that join two or three teeth, which is the result of an exact three-dimensional copy of the teeth in the full denture of a totally edentulous patient (Figs. 24 and 25).

As a summary, by means of this GUi2 element, we convert a totally edentulous patient to a partially edentulous patient. Once scanned, with the IO scanner, this file is imported, allowing planning through the use of guided surgery software. As planning files, this software uses the SLT file from the intraoral scan of the patient with the GUi2 element in place and the DICOM file from the computed tomography scan of the patient with the radiopaque GUi2 element in place.

The GUi2 element is therefore a radiopaque splint produced from a partial digital copy of the complete prosthesis of the patient. It only contains the teeth we consider of strategic importance in order to be able to:

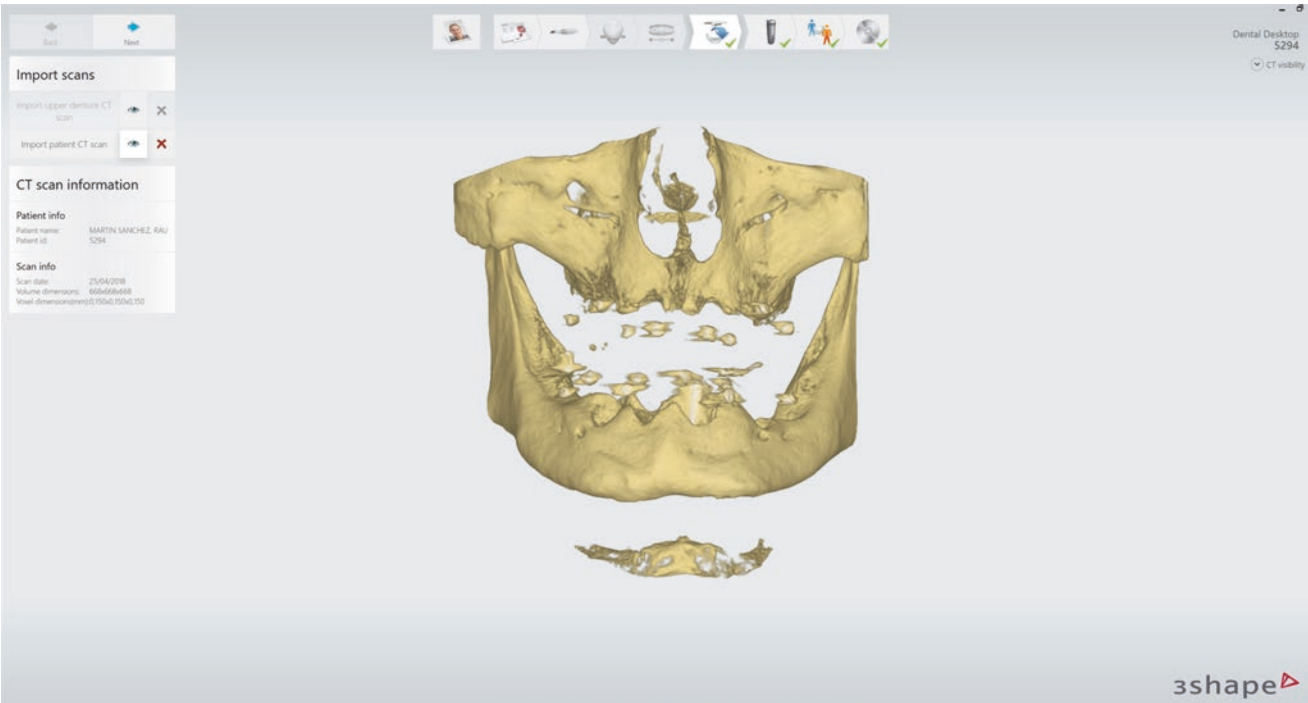

Fig. 4 The patient CT wearing the denture and radiopaque markers is imported on the guided surgery software

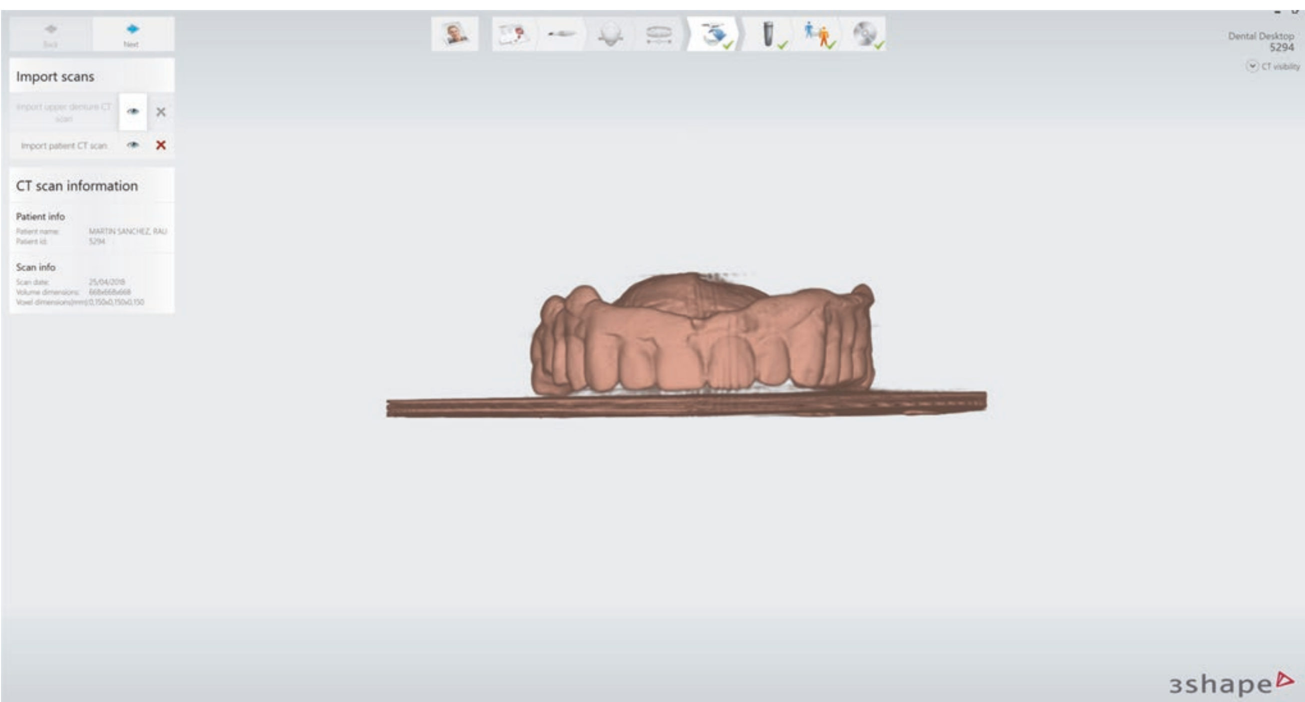

Fig. 5 Also the CT of the denture (with markers) alone was imported and

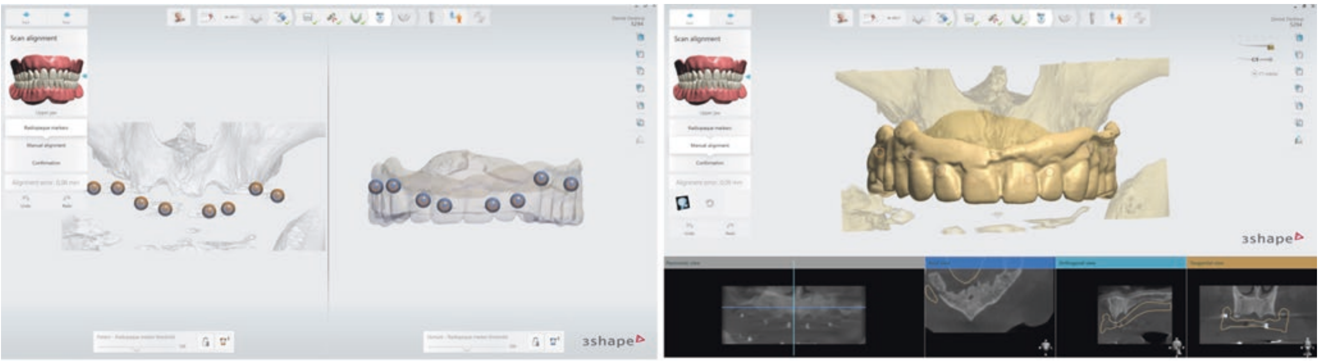

Fig. 6 Thanks to the presence of this radiopaque markers on both CTs, both files are merged

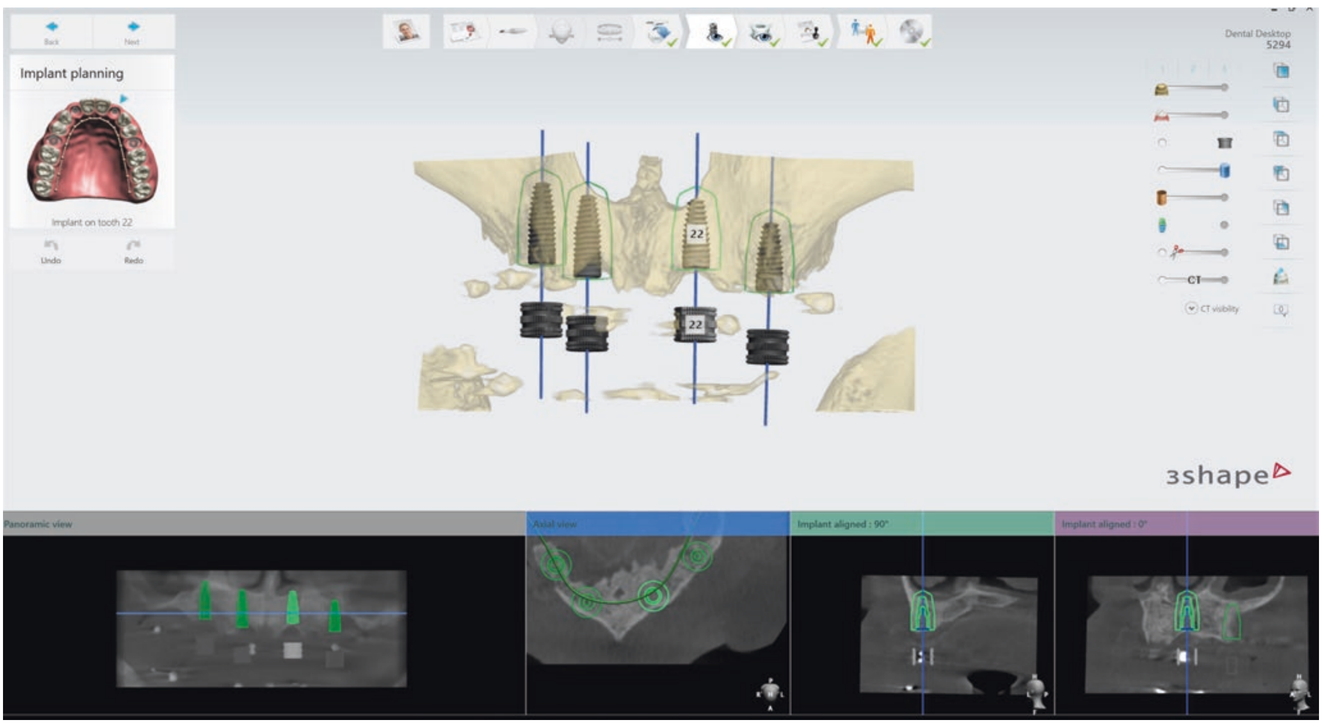

Fig. 7 On the final file, a virtual implant placement was done. Bone availability, relationship to the complete denture, bone density, guided sleeve position, and constant looking for the best parallelism between all the implants are mandatory factors when selecting implant locations

1. Transmit the esthetic and functional information of the patient to the laboratory and guided surgery software.
2. Perform alignment between the intraoral scan of the patient with the GUi2 element in place and the computed tomography file of the patient with the GUi2 element in place. In other words, the STL file is aligned with the DICOM file using the GUi2 element as common component between both files.

In order to develop the GUi2 element, we start from a complete prosthesis that is perfect in terms of support on the mucosa, esthetics, and function. After accepting such esthetics and function provided by the complete prosthesis, we move on to the initial workflow for creation of the GUi2 element.

This can be done in two ways:

1. Conventional: As a copy of the complete denture of the patient, followed by elimination of the zones in the radiopaque copy that cover the gums that will receive the implants and the non-strategic teeth. This copy can be obtained by conventional laboratory techniques or laser scanning. Production of the GUi2 element is therefore done manually or on a CAD-CAM final environment.

A full digital workflow is advised in order to secure maximum accuracy. For this purpose, we again use the i2 element (see Chap. "The i2 Protocol for Digital Immediate Loading

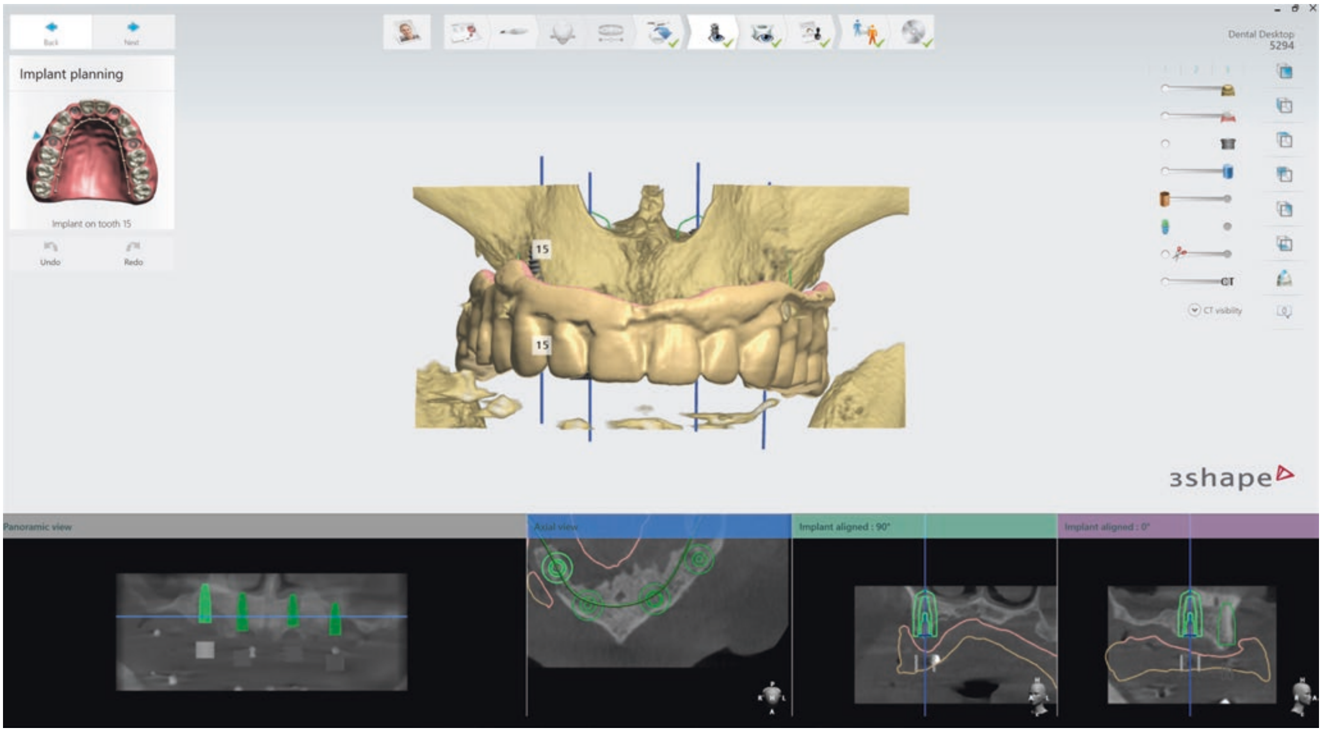

Fig. 8 The working file contains the complete denture of the patient, so we can visualize the proposed exit of the prosthetic screws

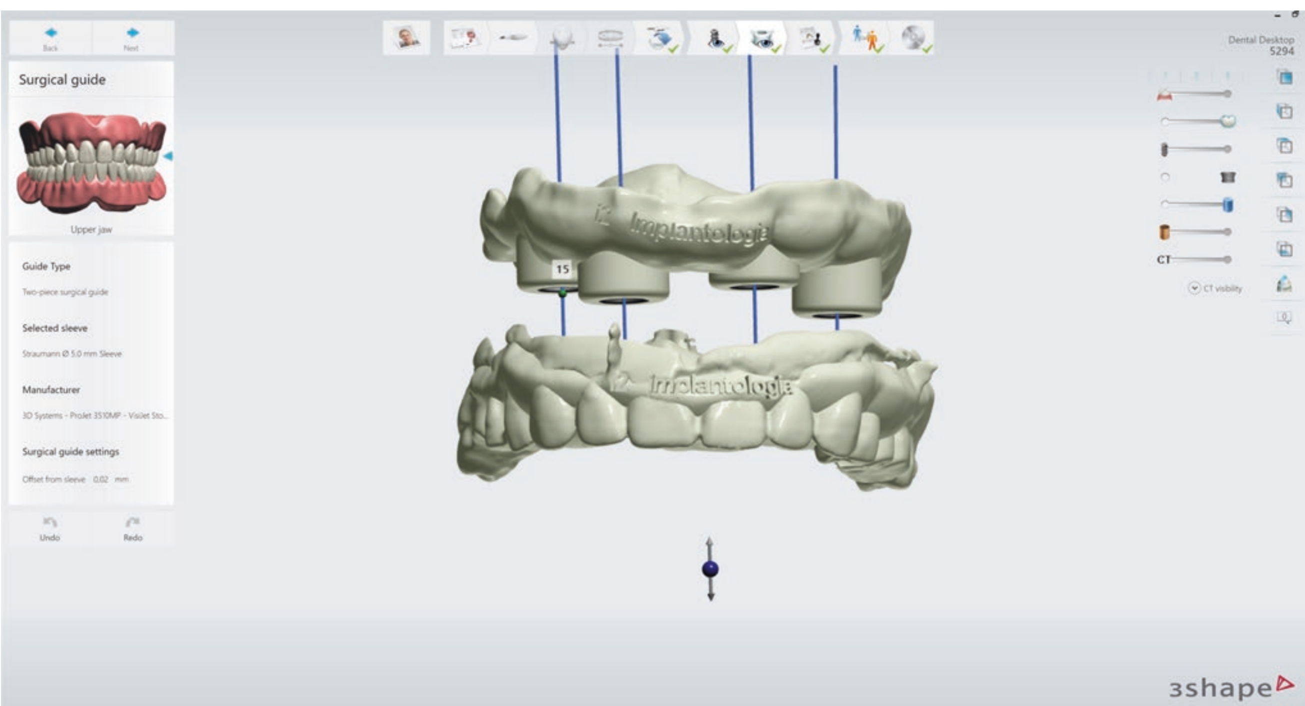

Fig. 9 The guide is designed in two pieces. Being a copy of the CT file of the denture, this design allows a secure placement of the guide on the jaw to be treated by means of the patient's bite. On surgery, the patient firmly in position bites the guide, allowing us to fix the primary part of the guide (the one containing the guide sleeves) to the jaw

Fig. 10 The file containing the final implant position is sent to the lab. Using the presence of the complete denture as a pre-preparation, the lab technician can easily design the temporary prosthesis

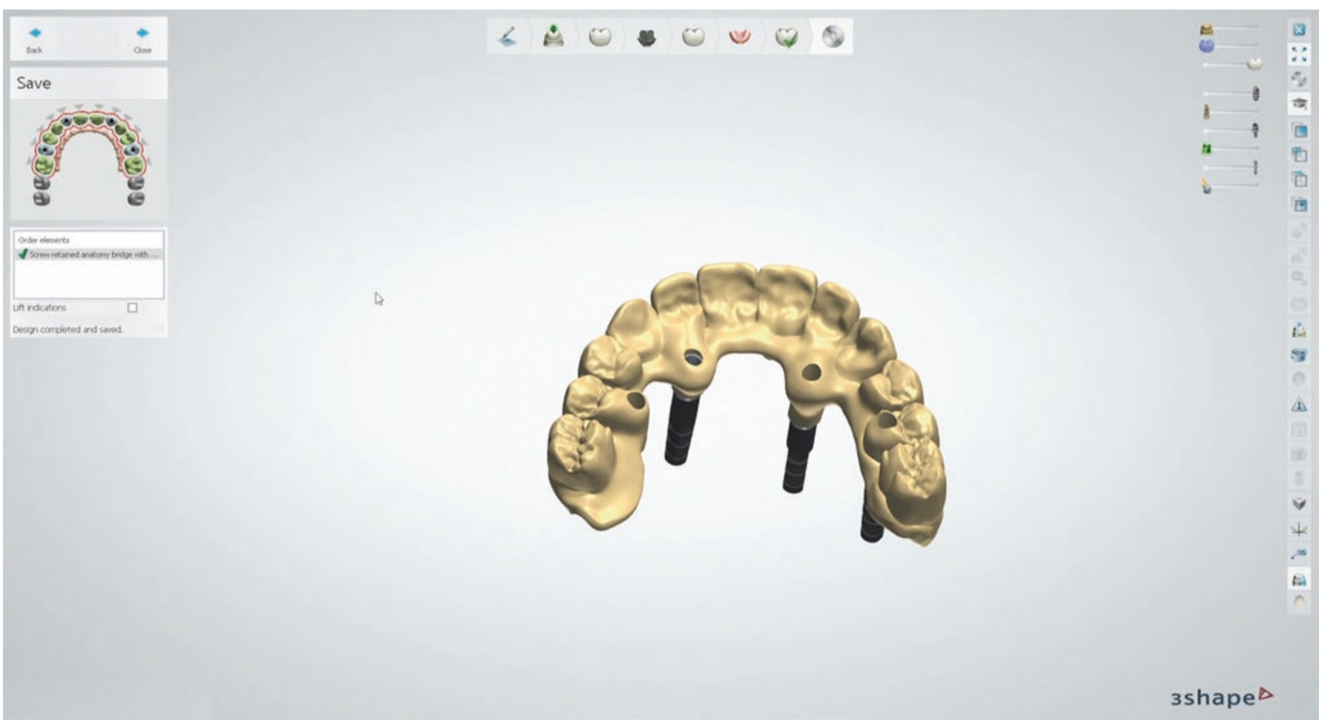

Fig. 11 The final file of the temporary to be milled

Fig. 12 The printed guide. Both pieces are mounted

Fig. 13 Showing both pieces of the guide

Fig. 14 Two pieces' guide

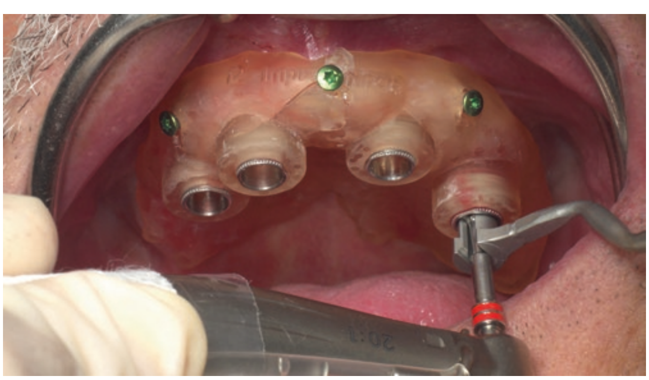

Fig. 15 The guide secured on the upper jaw with fixation screws. Performing surgery

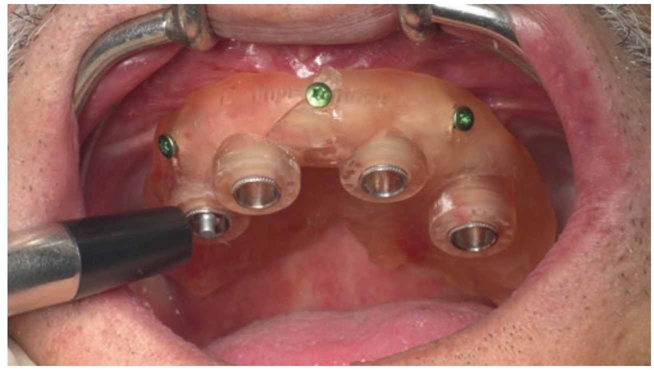

Fig. 16 After the guided implant placement and before removing the guide, ISQ levels of all the implants are taken to document the case

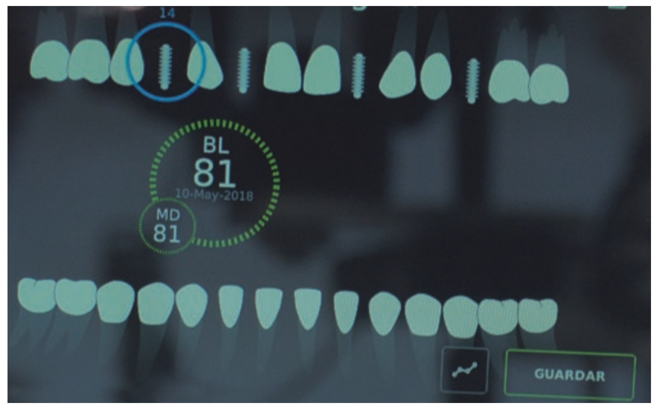

Fig. 17 High ISQ levels are obtained thanks to an oriented immediate loading surgery

Fig. 18 The guided temporary prosthesis was already done before surgery. Just after removing the guide, it is presented and fully seated on the implants, checking for a perfect passive fit

in Totally Edentulous Patients: Non-guided Treatment Protocols") as alignment component of several intraoral scans (Figs. 26 and 27).

We first produce one or two orifices in the complete prosthesis of the patient, over the zone of the maxilla where we strategically wish to place the i2 element. With this orifice we position the prosthesis in the patient and mark the mucosa where we plan to place the i2 element. Posteriorly, we remove the prosthesis and place the i2 element in the max-

Fig. 19 A final characterization is done, adding artificial gingiva for lip support and enhancing esthetics

Fig. 20 Once processed the guided prostheses are ready to deliver to the patient

Fig. 21 Final intraoral appearance with the temp guided prostheses

illa. With the i2 element in position in the edentulous maxilla, we scan the patient (file 1).

Then, we again position the prosthesis in the patient, and without removing the i2 element, we perform another intraoral scan (file 2). This file contains the positioned i2 element (or elements) together with the patient prosthesis, the antagonist, and the bite.

Both files (file 1 and file 2) are sent to the laboratory, where the technician can align them using the i2 elements as reference.

Fig. 22 Final appearance of the patient with the temp guided prostheses

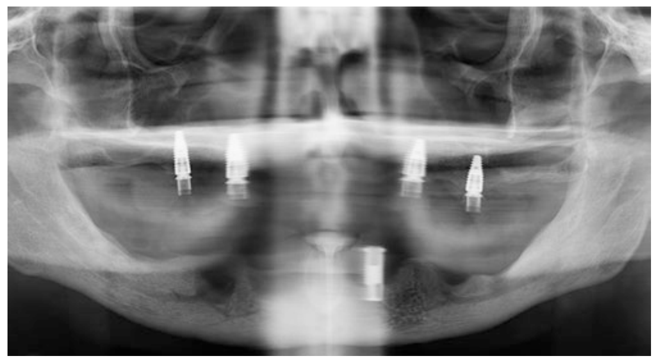

Fig. 23 Post-op immediate OPG showing the passive fit of all the ti-bases

In this way the software of the technician contains the scan of the edentulous maxilla and of the complete prosthesis of the patient, duly aligned. The technician is able to design the GUi2 element selecting and copying, the esthetics and spatial-functional position of the teeth, the technician wants to appear in the new radiopaque splint. These teeth are joined by connectors that should not occupy the gingival position where the implants will be placed in the guided surgical procedure. Ideally, moreover, selection should be made of those teeth not located over possible implant receptor sites.

Production of the GUi2 element is made by milling from a barium resin disc or through three-dimensional printing using barium resin.

In this way we obtain a radiopaque element fitted to the maxilla and transforming the patient into a partially edentulous individual ready both to be scanned with the intraoral scanner and to undergo the exploratory computed tomography scan for guided surgery.

The GUi2 element is affixed to the maxilla with adhesives or an osteosynthesis screw, and we obtain the intraoral scan of the maxilla, the antagonist, and occlusion. Then, without removing the GUi2 element, the computed tomography scan is performed.

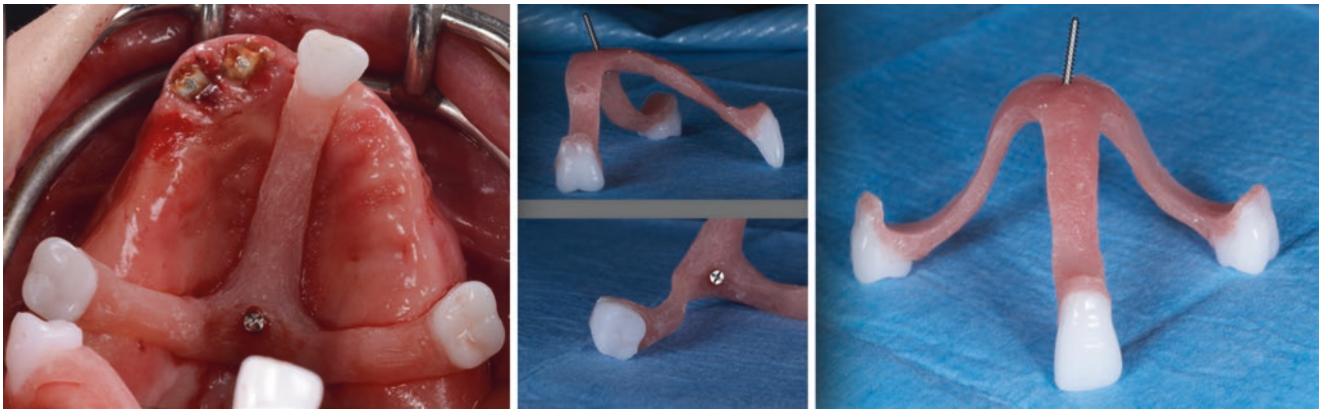

Fig. 24 A conventional Gui2 (non-digital)

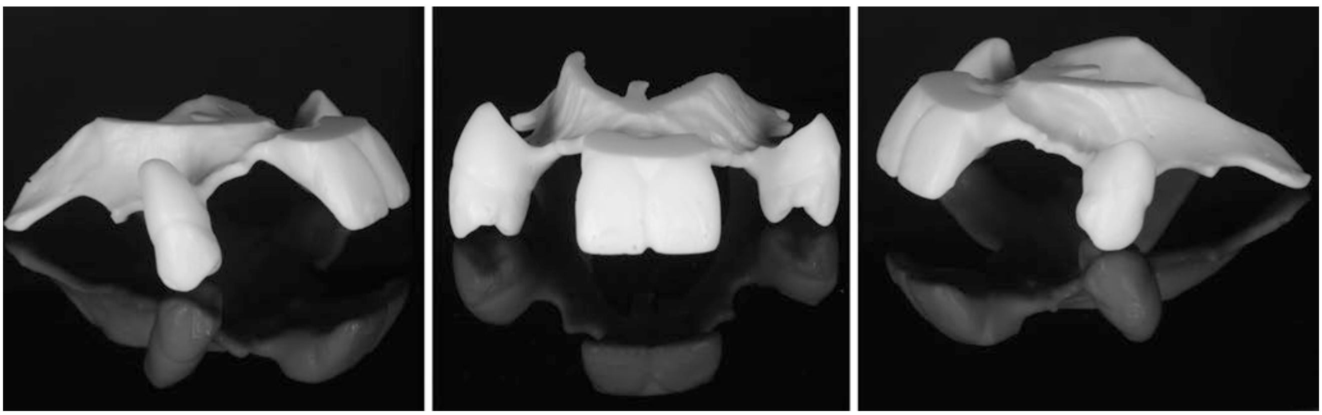

Fig. 25 A full digital Gui2 milled out of a disc of radiopaque (barium) resin

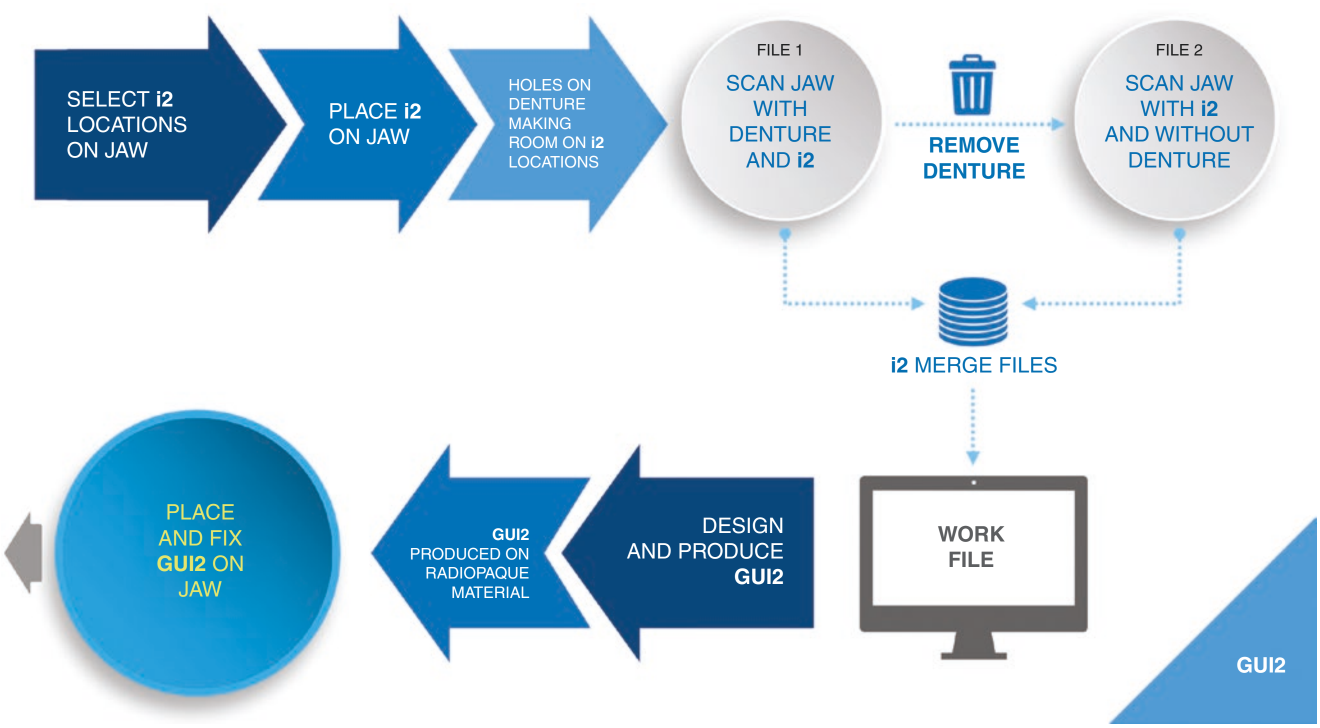

Fig. 26 Flowchart of a full digital Gui2 workflow. Initial steps create the Gui2

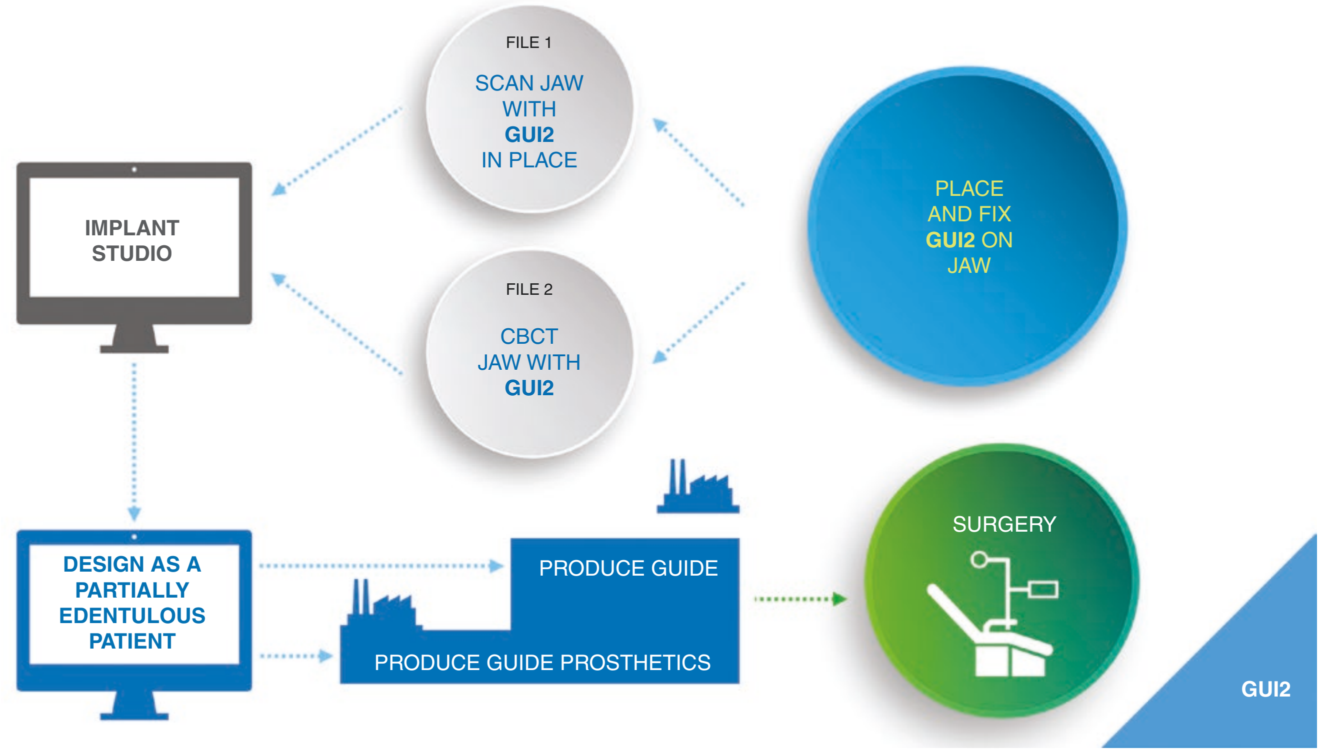

Fig. 27 Flowchart of a full digital Gui2 workflow. Final steps, once placing the gui2, scan and make the surgical plan

These two files (intraoral scan and computed tomography scan) are imported to the guided surgery software. We thus have the information referred to the patient gingiva without distortion, thanks to the intraoral scan of the GUi2 element placed in the mouth. We also obtain all the information of the patient referred to function, vertical dimension, occlusion, and esthetics (spatial position of the teeth in relation to the rest of the structures). Lastly, we have the bone data referred to the maxilla destined for treatment thanks to the computed tomography scan in which the GUi2 element also appears.

In order to plan with the guided surgery software, we align the two files (intraoral scan and computed tomography scan). Since these files both contain the GUi2 element (the latter being geometrically and radiologically visible in both files), the alignment best-fit points are positioned in the geometrically and radiologically significant zones we wish in both files. This results in perfect alignment allowing us to start planning the case conventionally.

We can design the surgical guide over the intraoral scan of the patient, thus obtaining perfect fitting of the guide to the gums and very high precision in guided implant placement.

The final product of the planning process comprises two files: one for printing the surgical guide and another to be transmitted to the laboratory software, for designing the guided prosthesis—creating the anatomy, esthetics, and emergence profiles, according to the information which the GUi2 element has entered in the software.

Thus, before starting the surgery, we have the surgical guide and the guided fixed provisional prosthesis to be fitted immediately after guided implant placement, screwed directly in place and without any modifications or direct rebase procedures, the guided prostheses. Once the procedure, surgery, and fitting the temporary has been completed, we obtain a panoramic radiograph to check correct fitting of the prosthesis on the implants or abutments.

In this way we are able to offer the patient an immediate fixed provisional prosthesis containing all the functional and esthetic information of his or her complete dentition. This prosthesis represents the initial model which we subsequently modify as considered opportune until the desired esthetic and functional outcome is achieved.

Case Presentation

A 68-year-old woman consulting after failing implants in both jaws. A guided prosthetics, including a full digital Gui2 procedure, was selected in the upper jaw (Figs. 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, and 58).

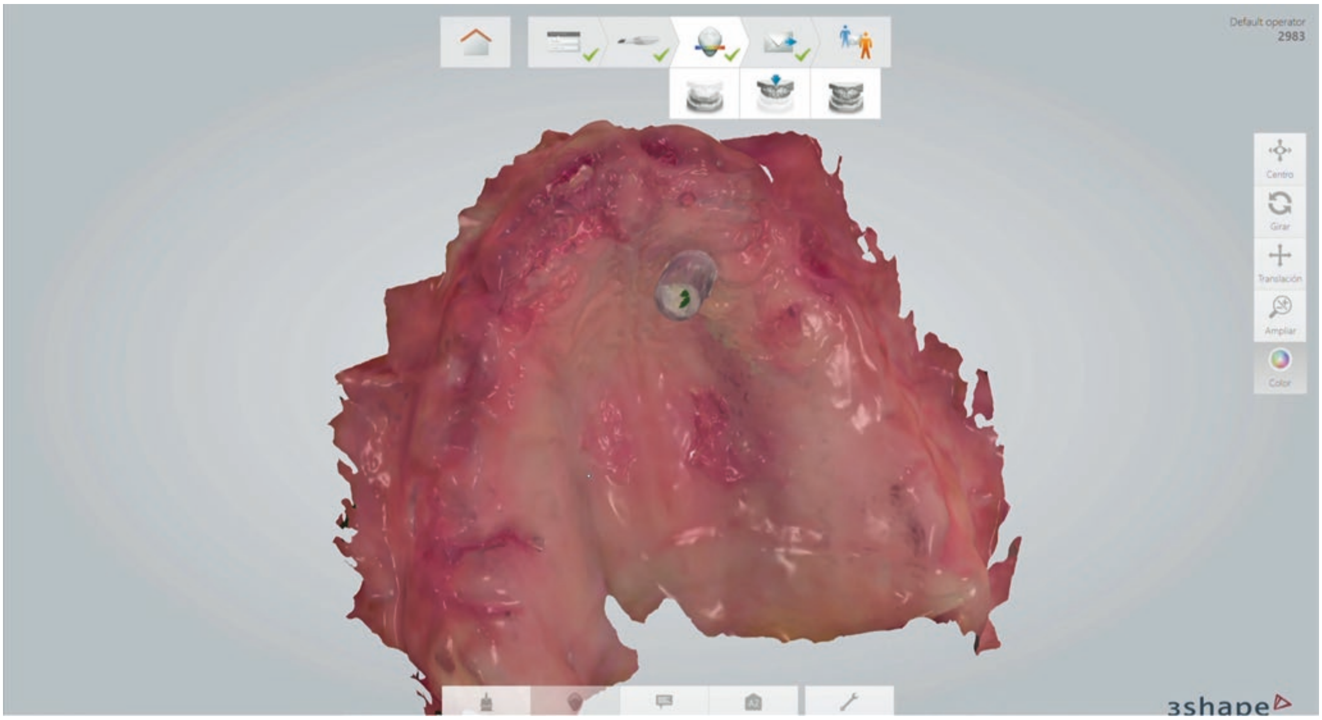

Fig. 28 An i2 device is placed on the upper jaw and a full arch scan is delivered

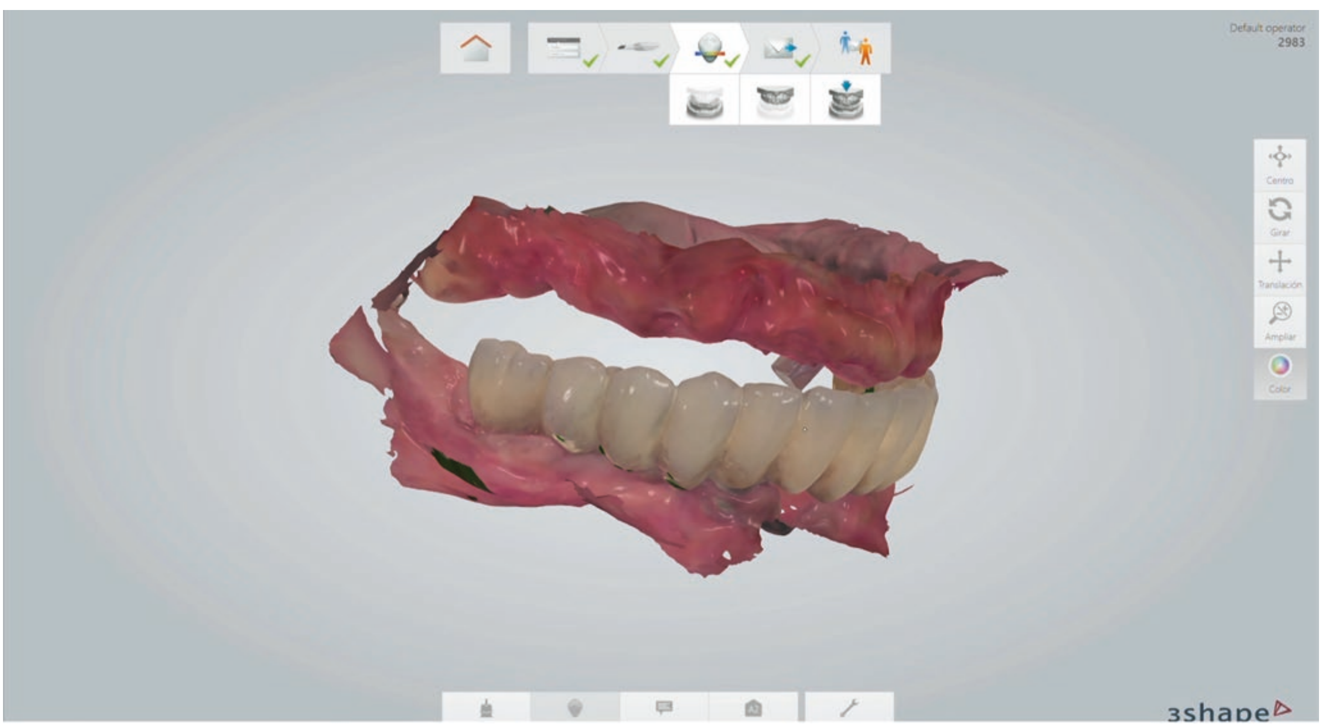

Fig. 29 Also the bite is on this file

Fig. 30 A second scan comprised the complete denture (trimmed to make room to the i2 device) and the i2 device

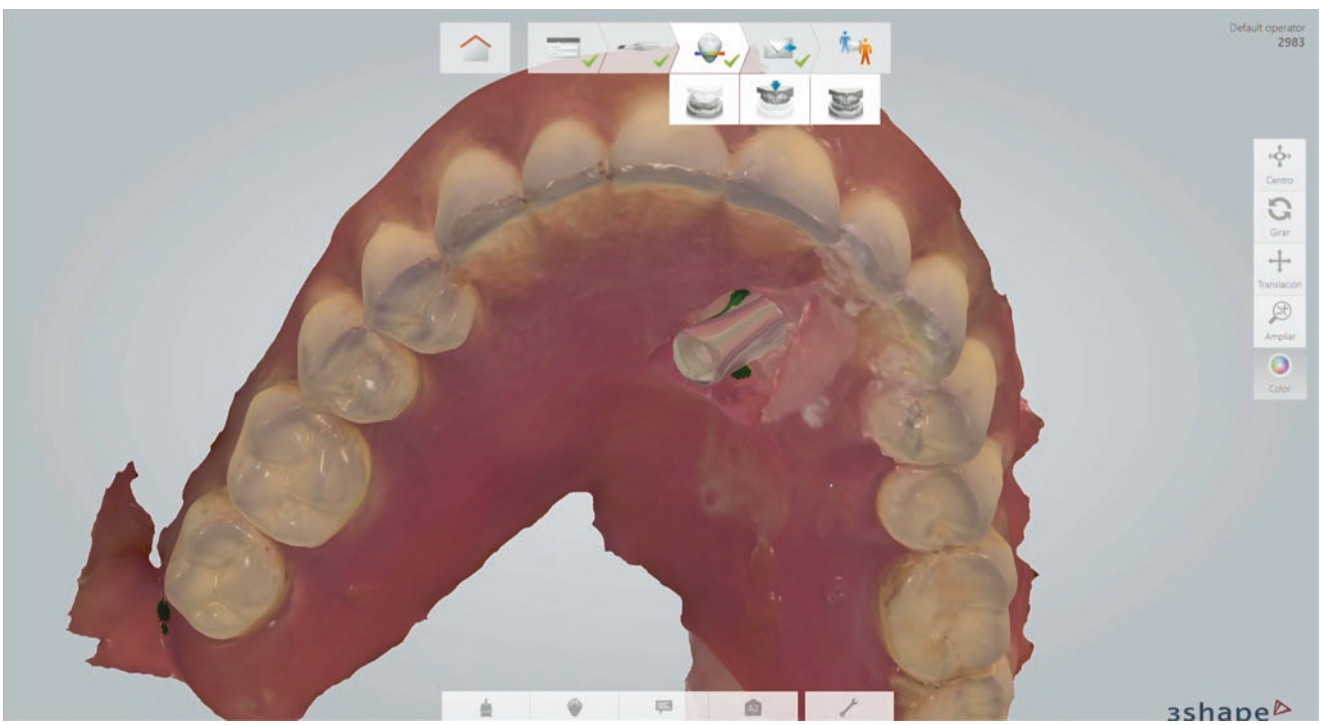

Fig. 31 Same file, different view showing the i2 in the same position as on the previous scan

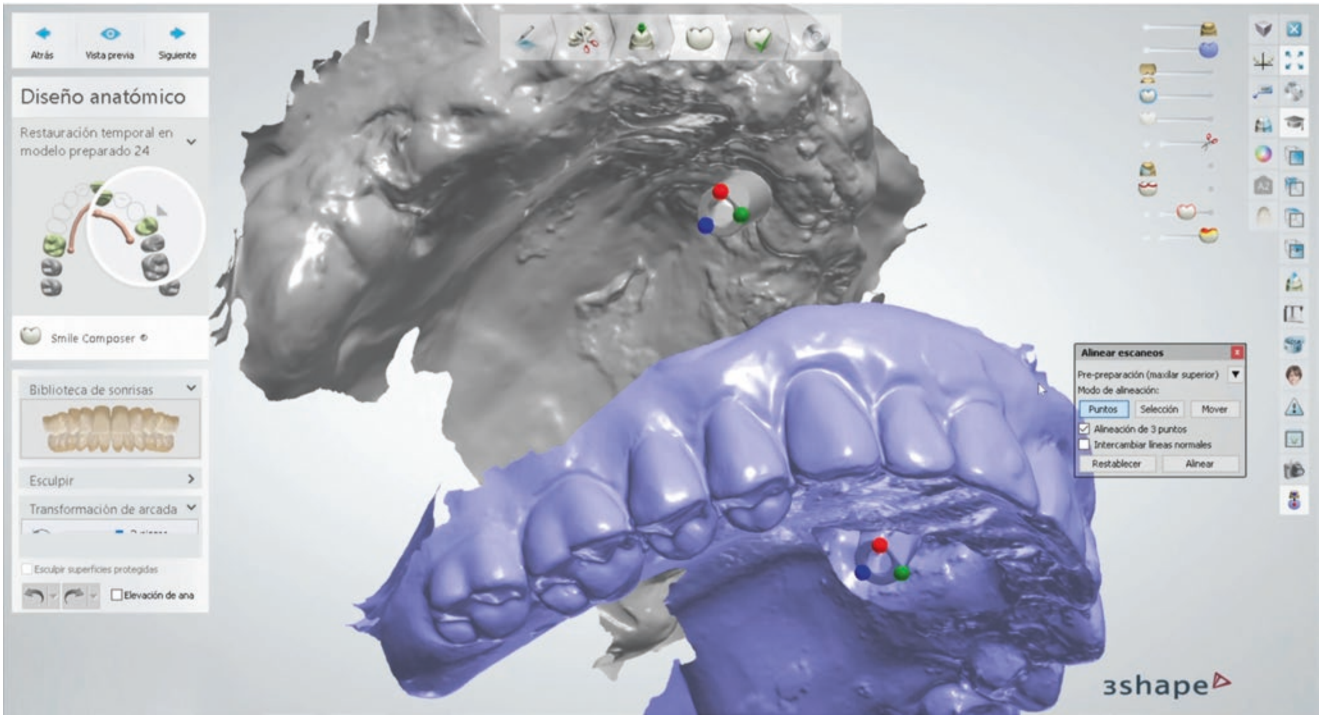

Fig. 32 Both scan files (they have in common the i2 device on the same position) are merged on the lab software by marking three merging points in the same position

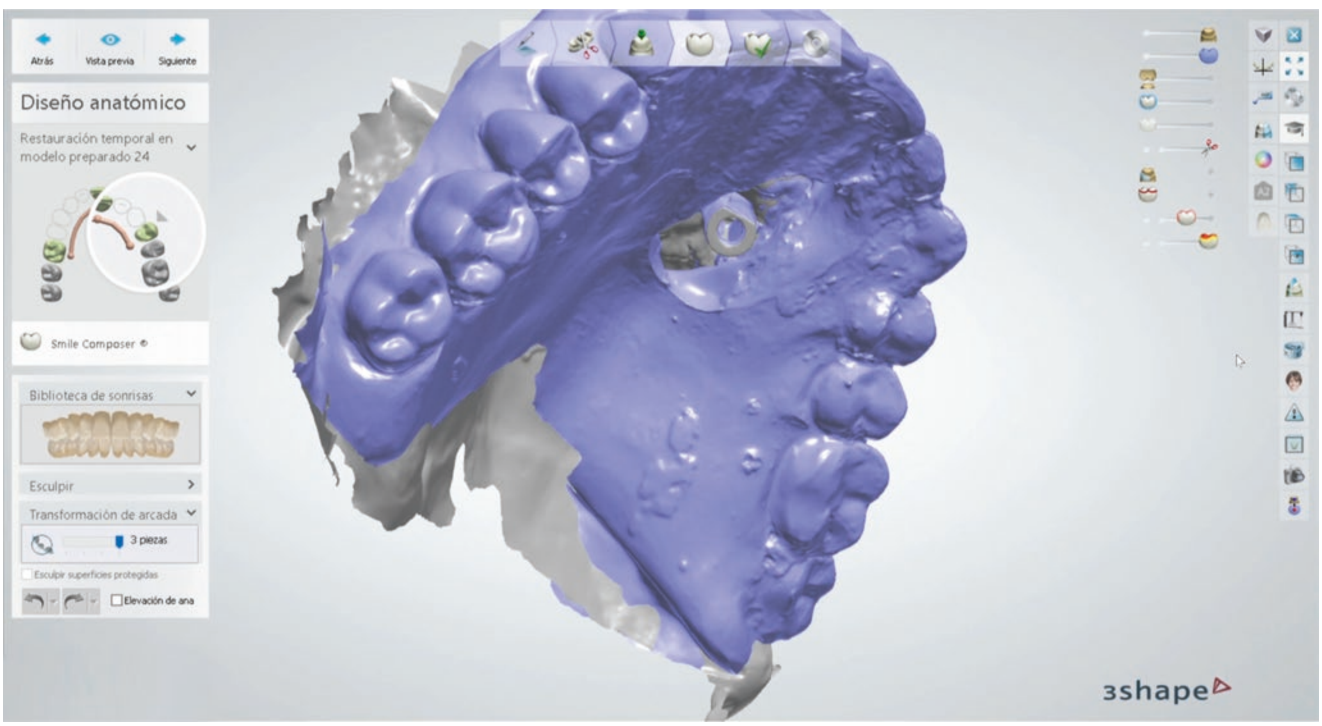

Fig. 33 Both files, merged, create a working file for the dental technician

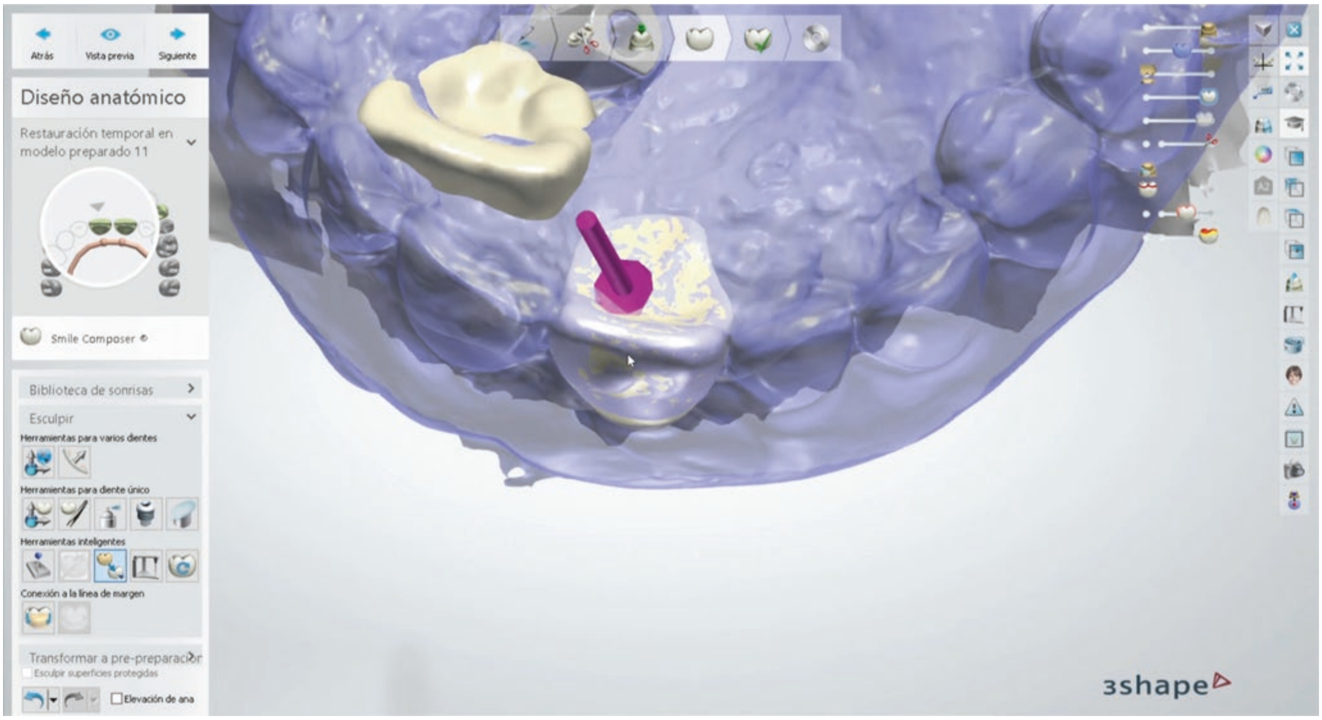

Fig. 34 The DT starts designing the Gui2, using, as a pre-preparation, the complete denture scan. Only three to four teeth are needed for a perfect workflow

Fig. 35 The final Gui2 design onto the complete denture scan

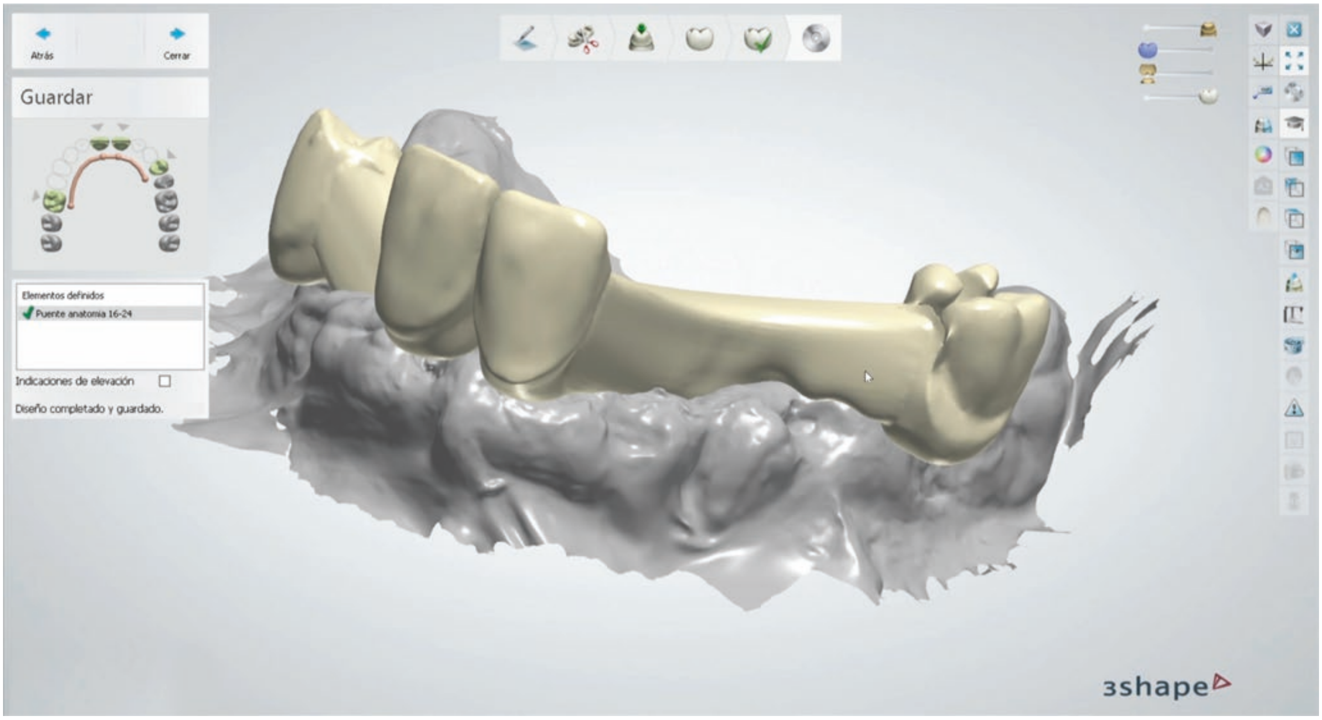

Fig. 36 The Gui2 designed, ready to be milled out of a block of PMMA with barium sulfate

Fig. 37 Patients preoperative OPG

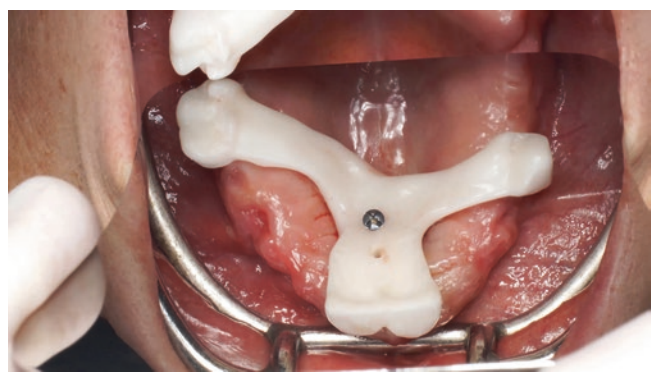

Fig. 38 The Gui2 is secured on the maxilla by means of a bone graft screw

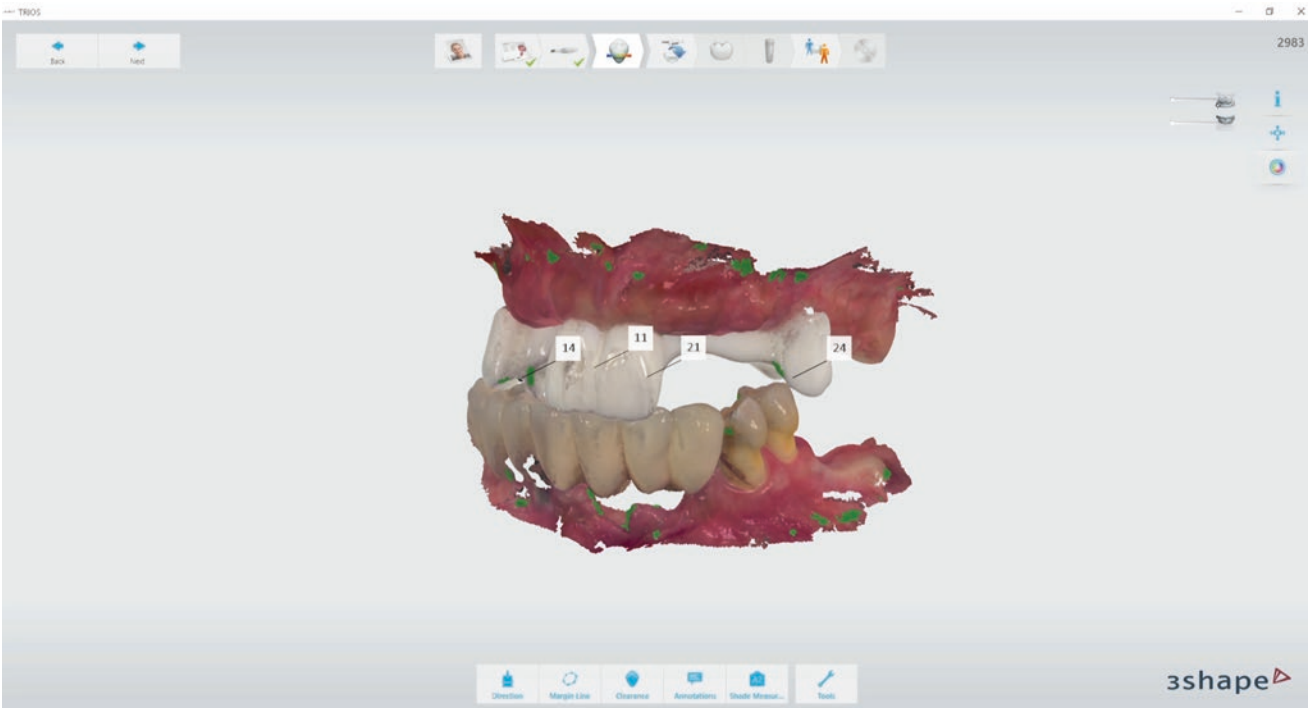

Fig. 39 Image of the scan file with the Gui2 in place. Now the patient's surgery and guided prostheses can be planned as a partially edentulous patient

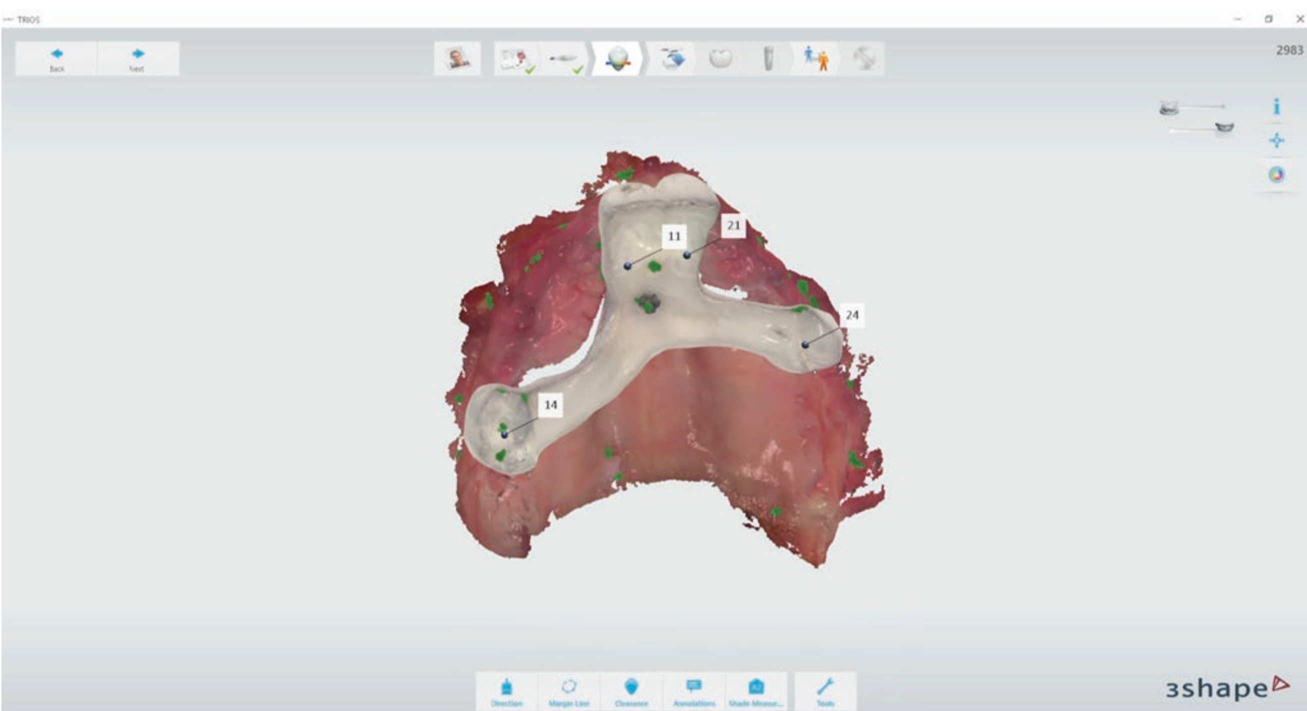

Fig. 40 Occlusal view of the same scan

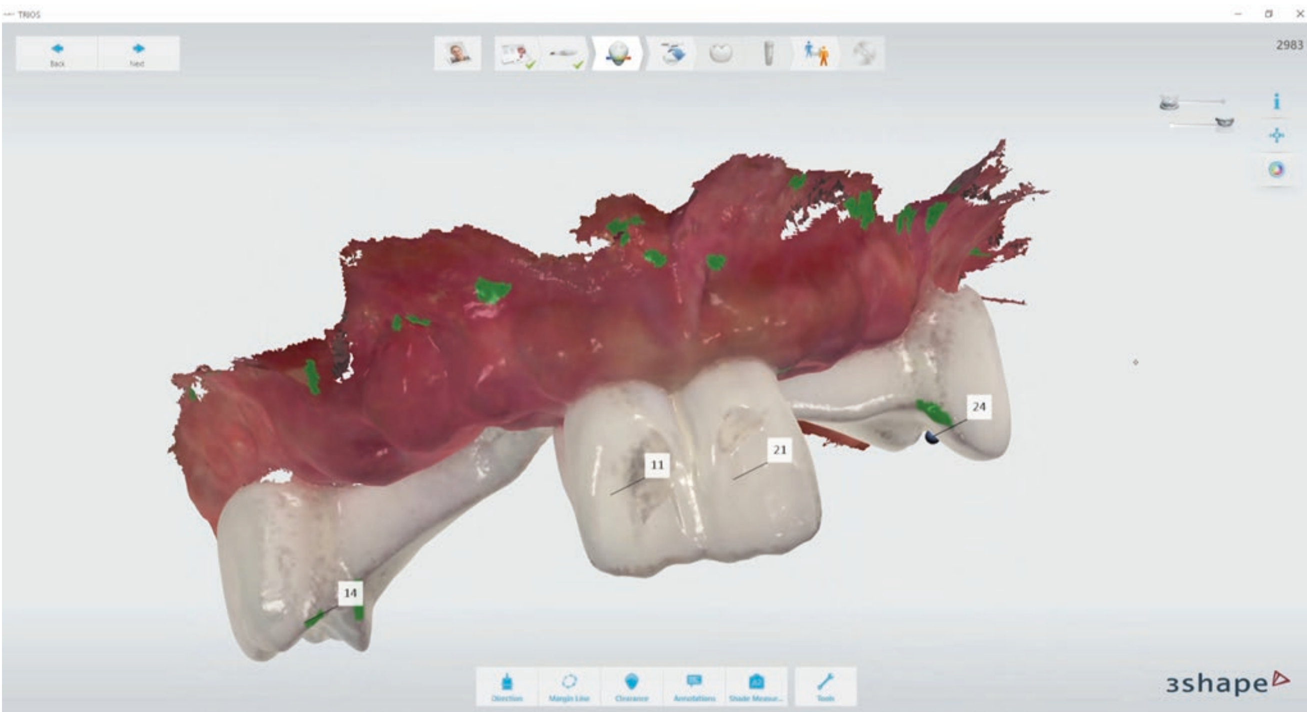

Fig. 41 Frontal view of the same scan

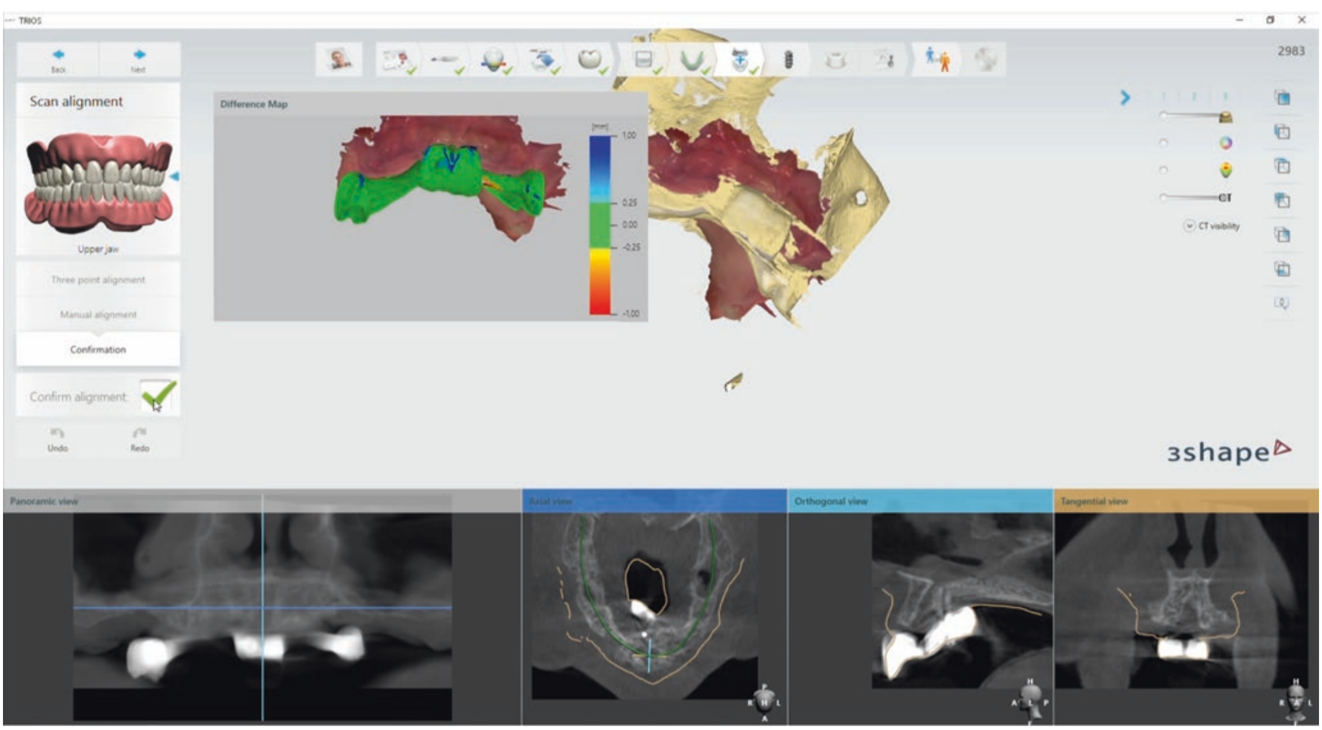

Fig. 42 After merging the CT file with the Gui2 in place and the intraoral scan file by means of the Gui2 device, the virtual placement of the implants can easily be done in the usual way

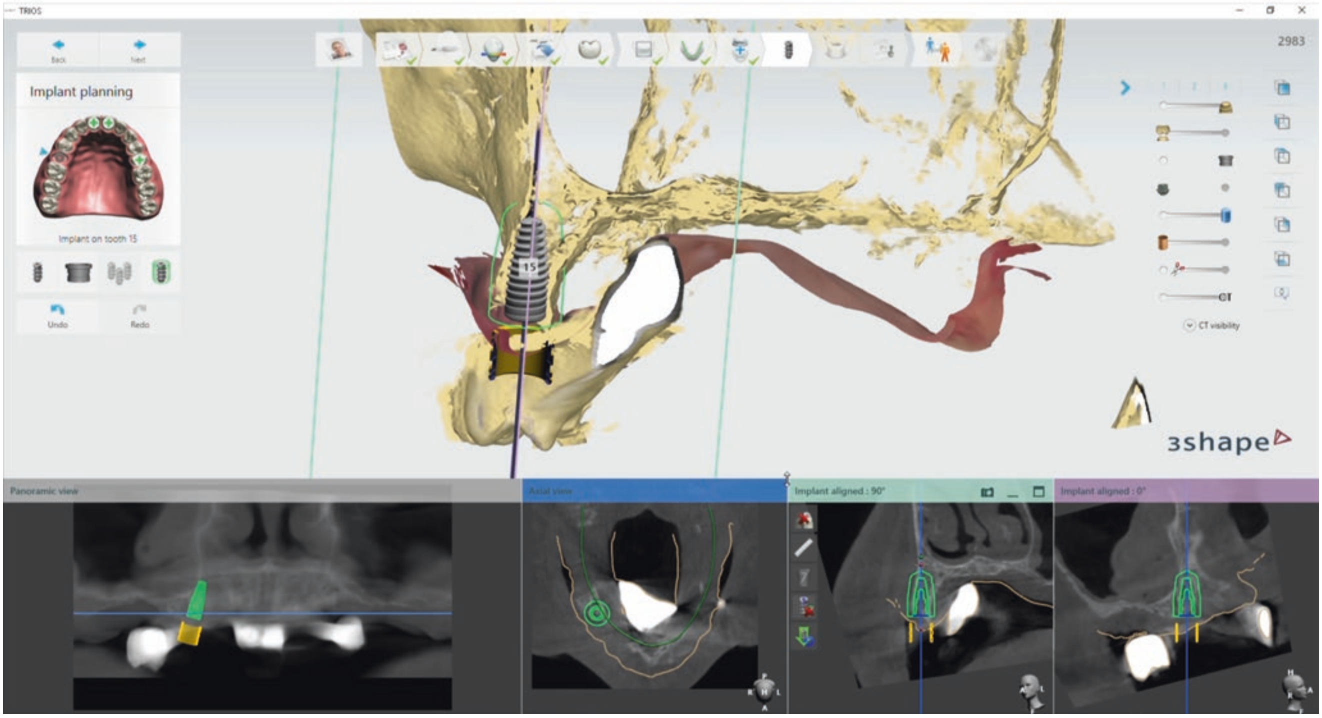

Fig. 43 Looking for the best parallelism and best implant locations is based on the bone morphology, availability, density, and from the prosthetic point of view by means of the Gui2

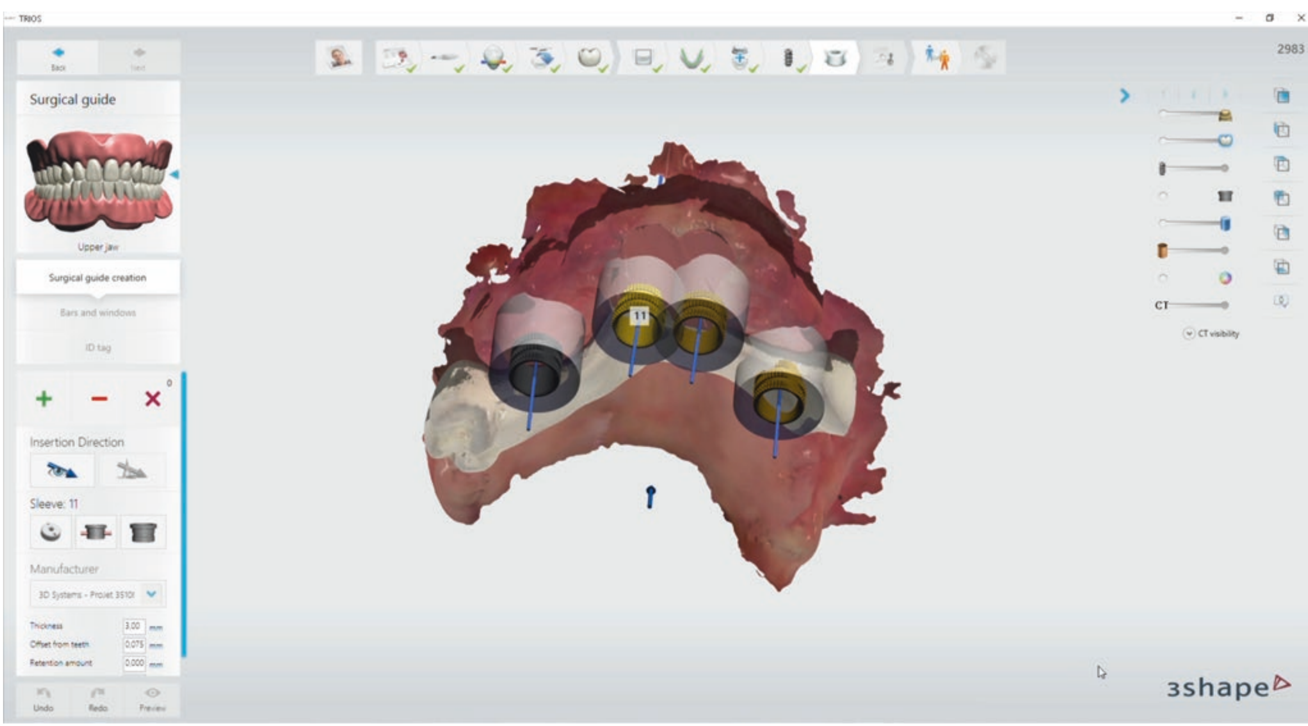

Fig. 44 The surgical guide is designed on the software after virtual removal of the Gui2

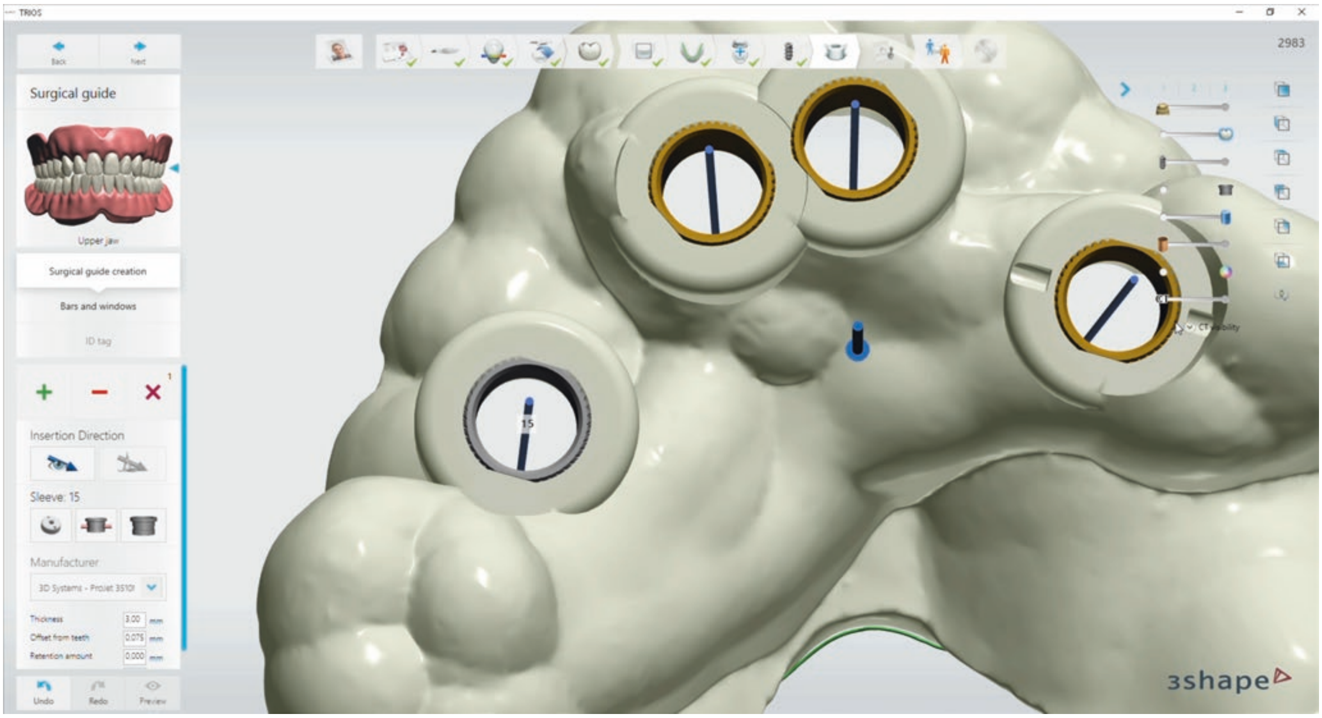

Fig. 45 Once planning is finished, a STL file of the guide is sent to be printed to create the surgical guide

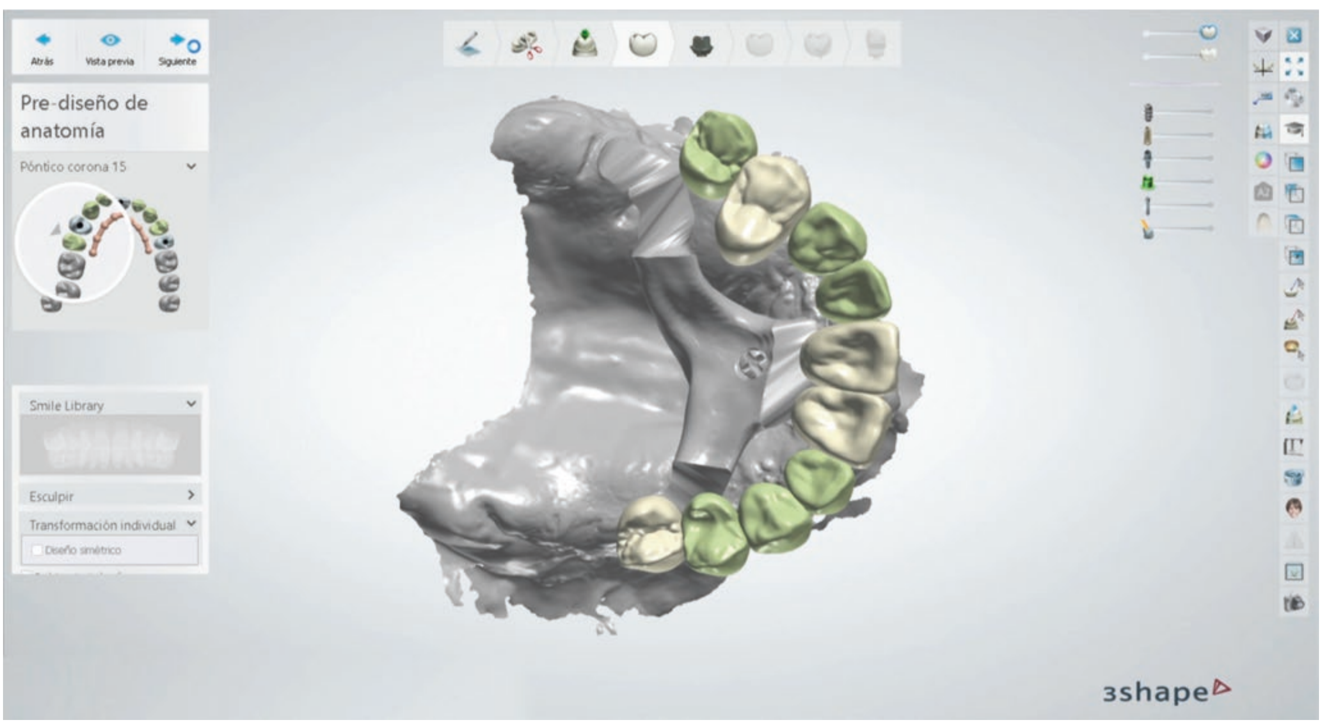

Fig. 46 Also the file with the proposed implant locations is sent to the lab to design the full arch temporary guided prostheses

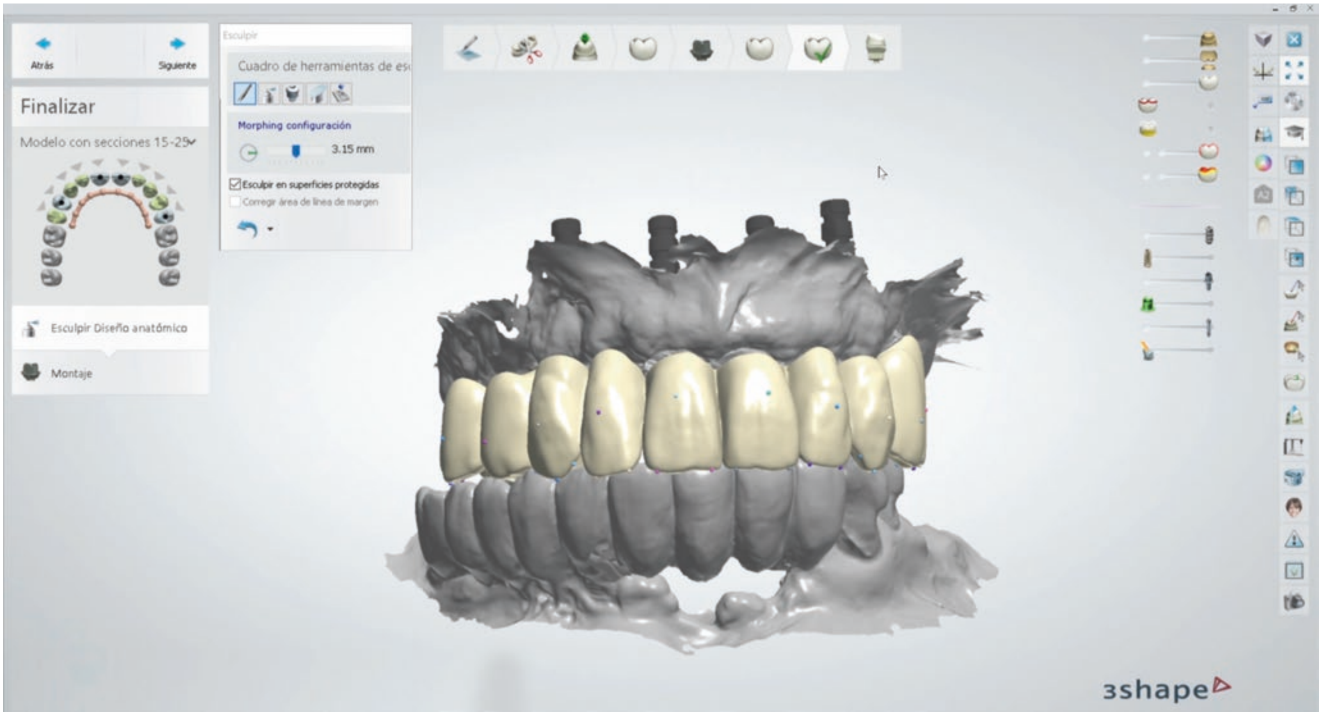

Fig. 47 The temporary already designed

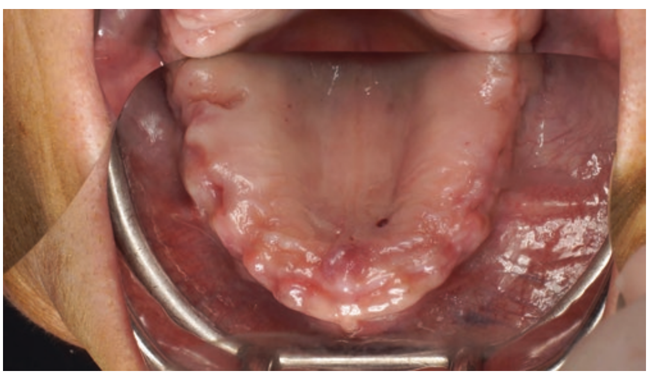

Fig. 48 Surgery: upper jaw to be treated

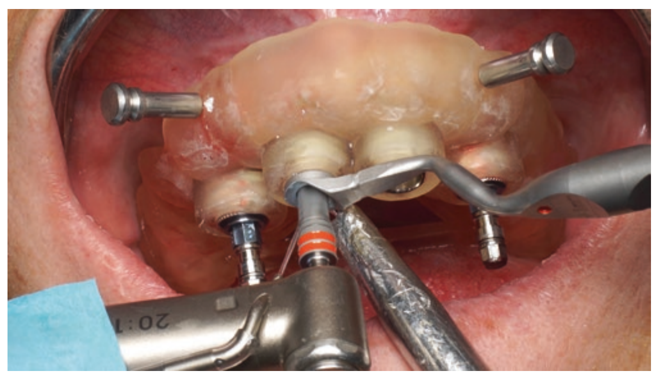

Fig. 50 Guided implant bed preparation

Fig. 49 The surgical guide

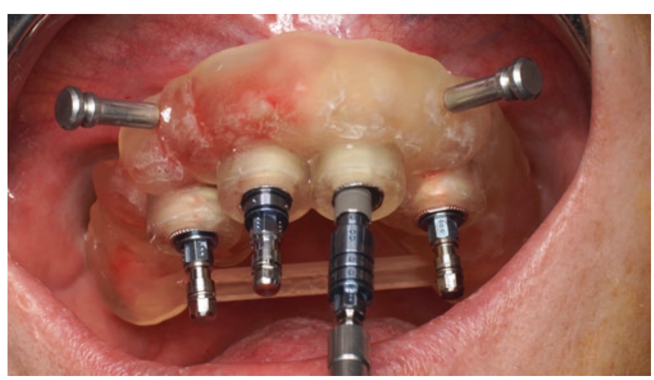

Fig. 51 Guided implant placement

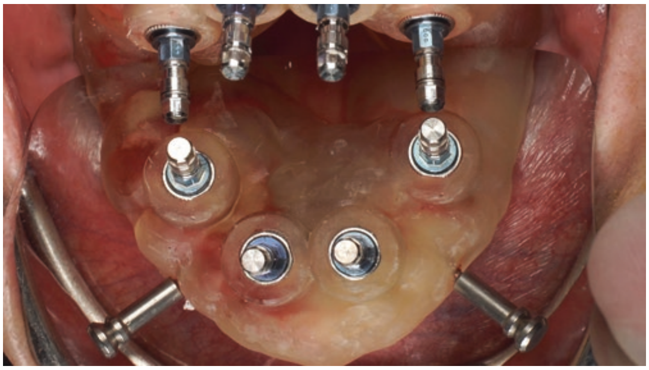

Fig. 52 Four implants placed

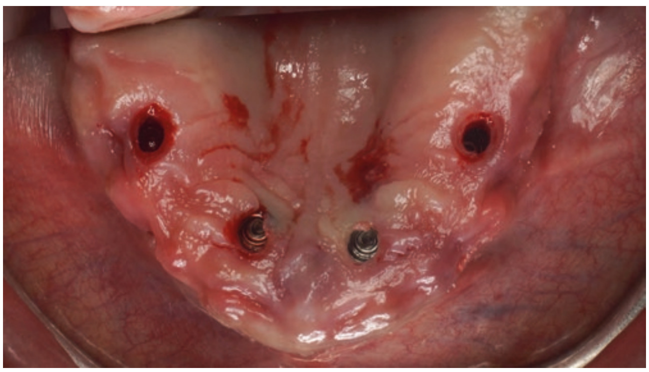

Fig. 53 After removal of the surgical guided, emergence profile is checked

Fig. 54 The milled before the surgery Telio CAD temporary guided prostheses, with ti-bases already glued, is seated on the freshly placed implants, without any modification. Check interferences with the soft tissue

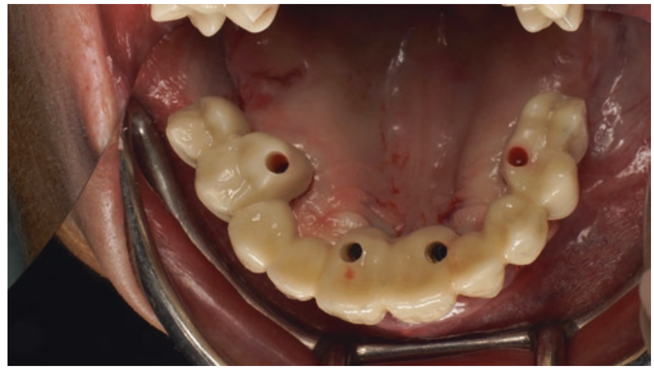

Fig. 55 Occlusal view of the full arch-guided prostheses in place

Fig. 56 Patients bite right after the temporary placement. Only minor modifications had to be done

Fig. 57 Immediate post-op OPG with the temp prostheses showing the perfect fit of the ti-bases on the implants

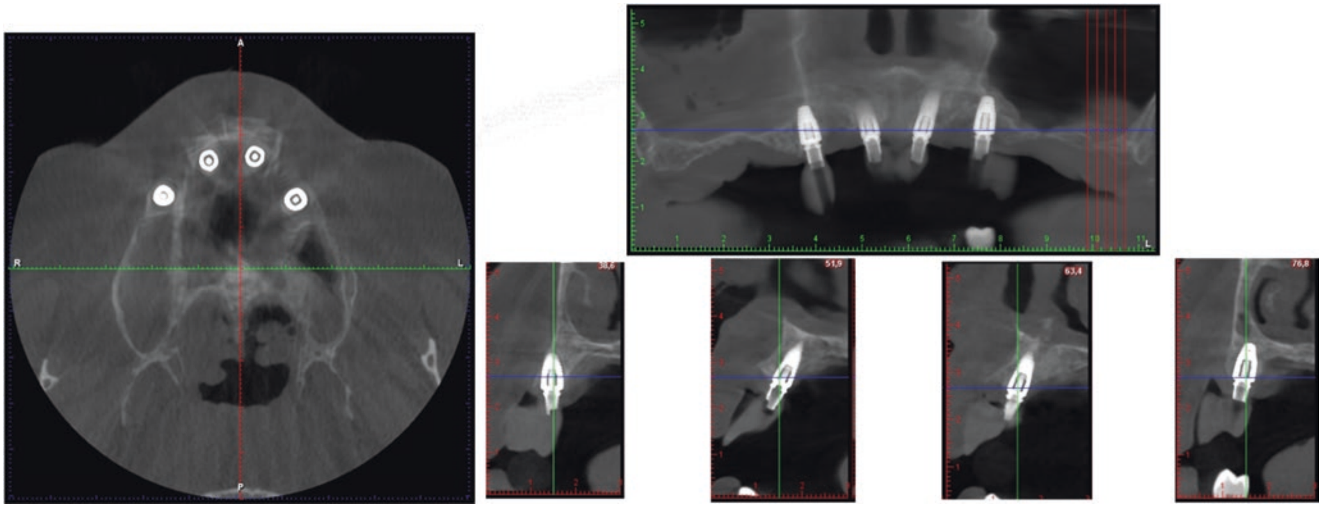

Fig. 58 A CT scan was done to confirm the perfect passive fit

i2 Mixed Technique: Guided Implant Placement or Drilling and Application of Any of the I2 Protocols

The mixed technique involves the following:

1. Planning of the case is carried out with the guided surgery software, creating a surgical guide allowing only initial drilling or also guided implant placement. We thus have greater guarantees in performing flapless surgery and the capacity to control implant angulation and parallelism.
2. Instead of preparing a guided prosthesis, we use any of the protocols described on Chap. "The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: Non-guided Treatment Protocols," to perform final scanning of the implants: i2 Standard, i2 Standard Plus, or i2 element.

In sum, the mixed technique only implies greater guarantees in implant placement and the possibility of performing flapless surgery in a larger number of cases.

Fig. 59 Same case Fig. 62 (Chap. "The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: Non-guided Treatment Protocols"). Upper jaw treatment. Preoperative appearance

Coming back to the case presented on Fig. 62 from Chap. "The i2 Protocol for Digital Immediate Loading in Totally Edentulous Patients: Non-guided Treatment Protocols," a mixed protocol was used to treat the upper jaw (Figs. 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, and 77).

Fig. 60 A conventional teeth try-in was created and placed in the mouth, and the study model scan was taken

Fig. 61 Surgery. By means of the guided surgery software, a surgical guide was printed. The guide is in position. A mixed soft tissue and dental support was elected for the guide in this case. Only the two upper canine were preserved

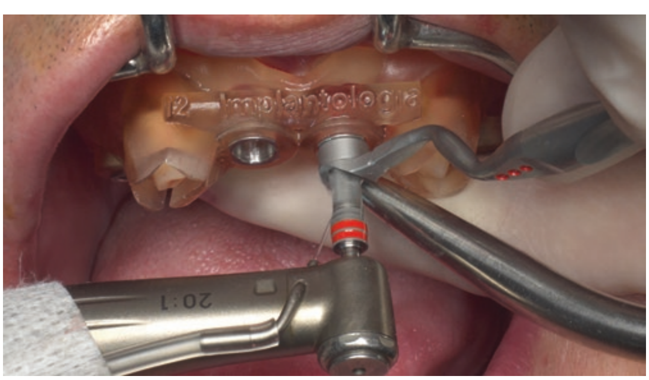

Fig. 62 Implant bed preparation

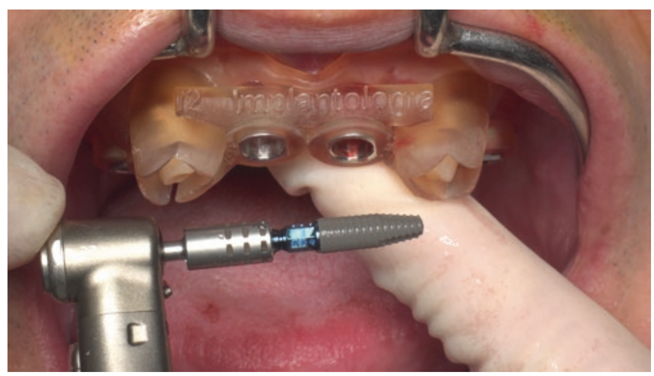

Fig. 63 Implant to be placed

Fig. 64 Guided implant placement

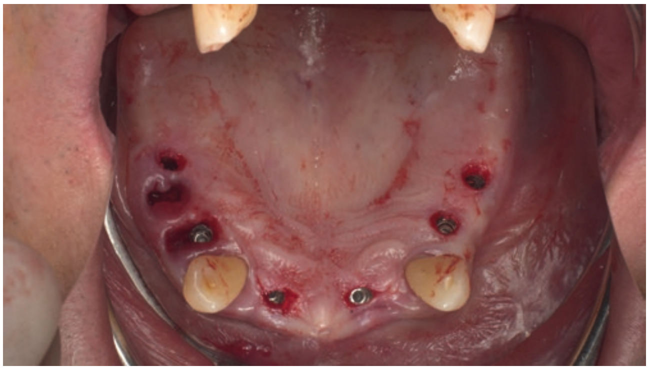

Fig. 65 Immediate appearance after removing the guide

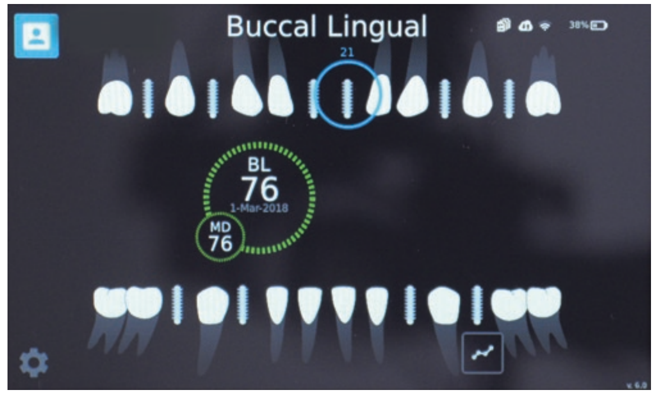

Fig. 67 Adequate ISQ levels for immediate loading

Fig. 66 ISQ levels are measured on all the implants

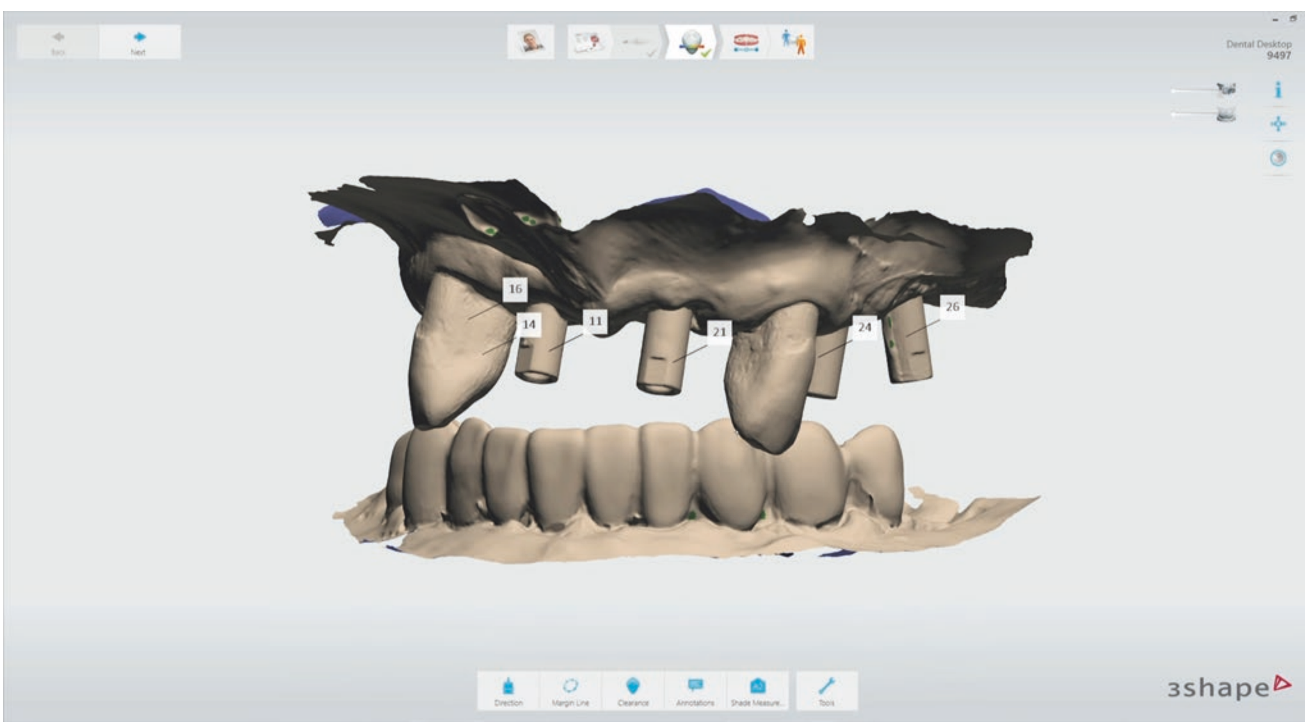

Fig. 68 Intraoral scan with the teeth preserved and the scan bodies to implant level

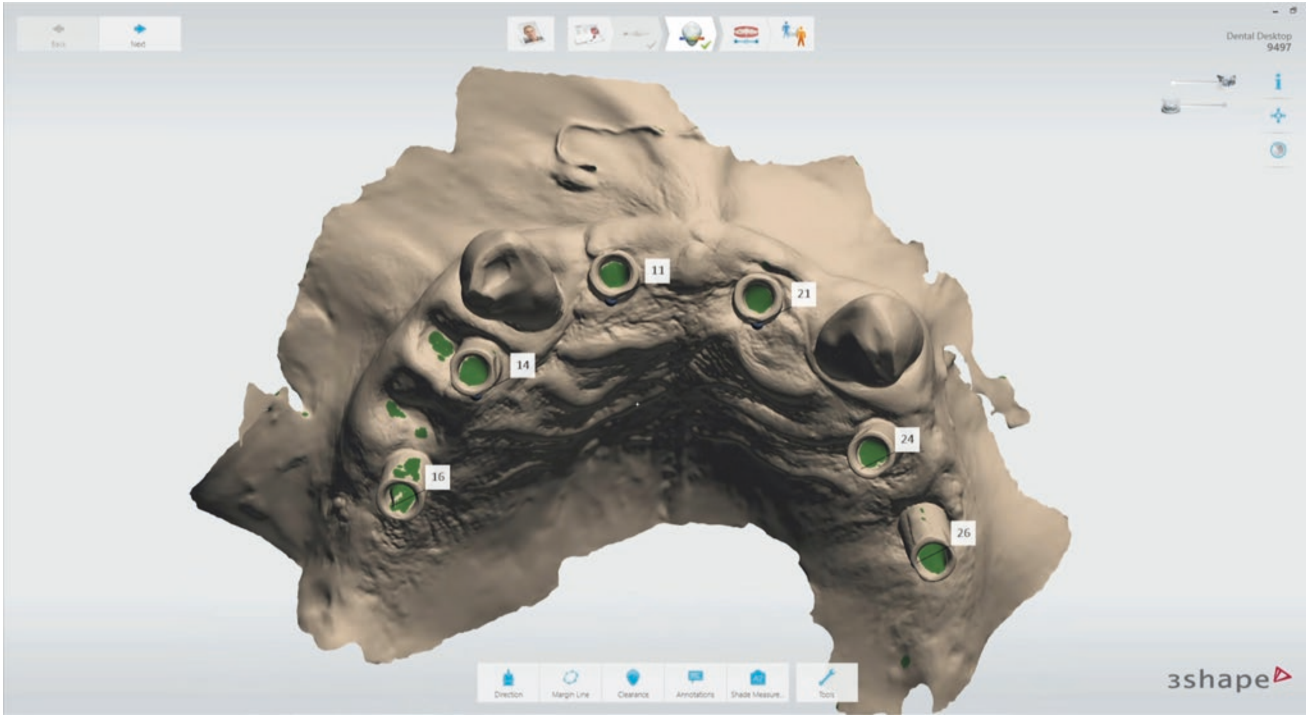

Fig. 69 Occlusal view

Fig. 70 By means of the preserved teeth, the study model scan, with the teeth try-in, and the surgical scan were merged

Fig. 71 Both files merged on the lab software

Fig. 72 Thanks to the study model scan, the immediate temporary full arch bridge can be easily designed

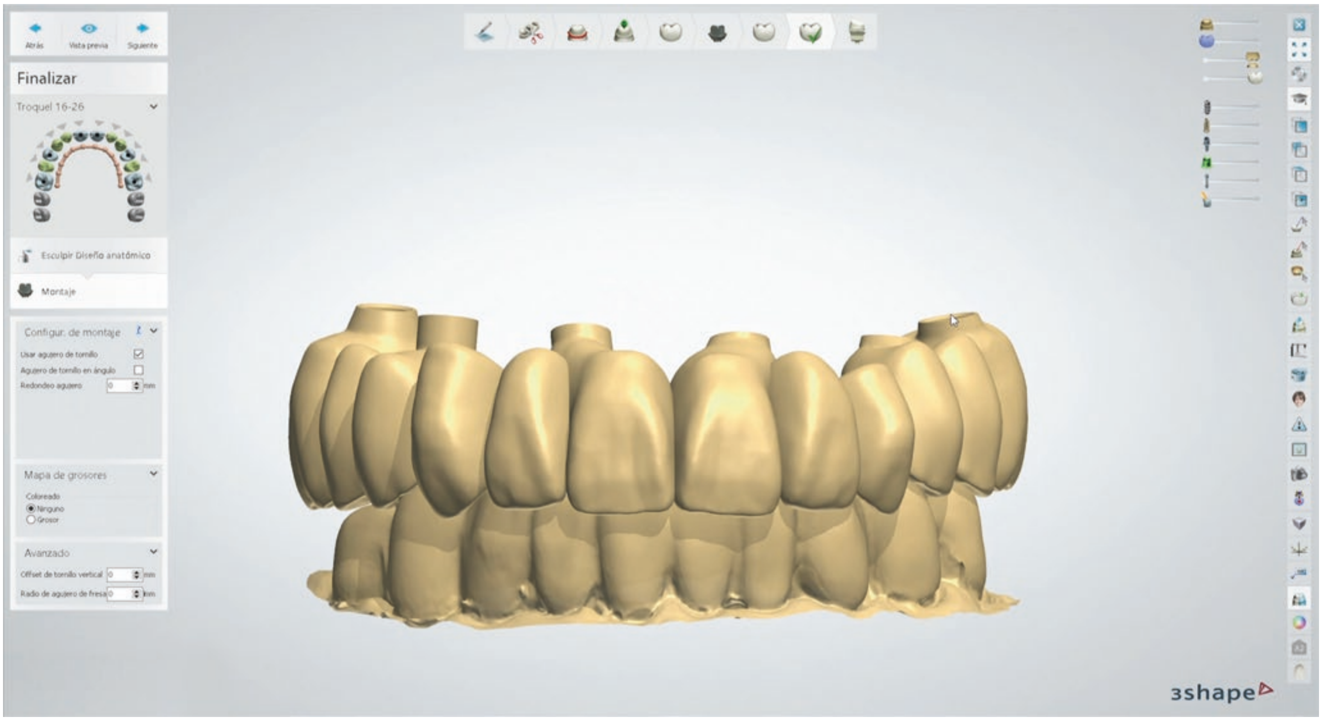

Fig. 73 Temporary bridge file ready to be milled

Fig. 74 After milling, characterization was done by the dental technician, ti-bases cemented

Fig. 75 Immediate same-day postoperative appearance with the temporary full arch bridge in place

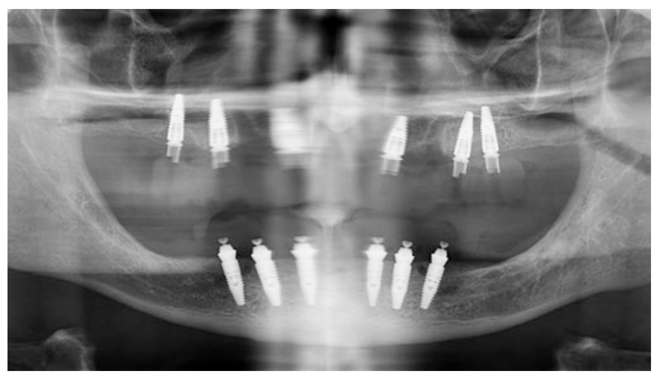

Fig. 76 Immediate post-op OPG

Fig. 77 One week appearance of the patient with both temporaries in place