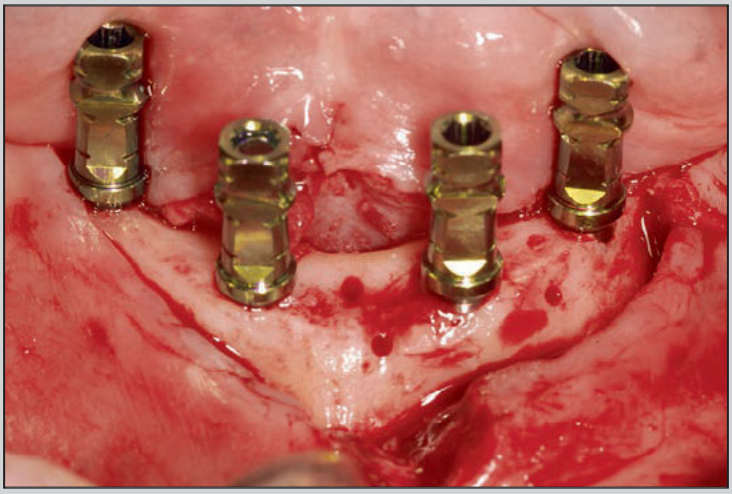
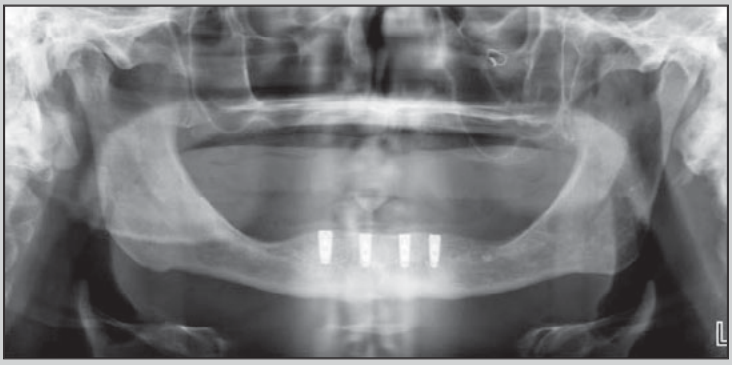
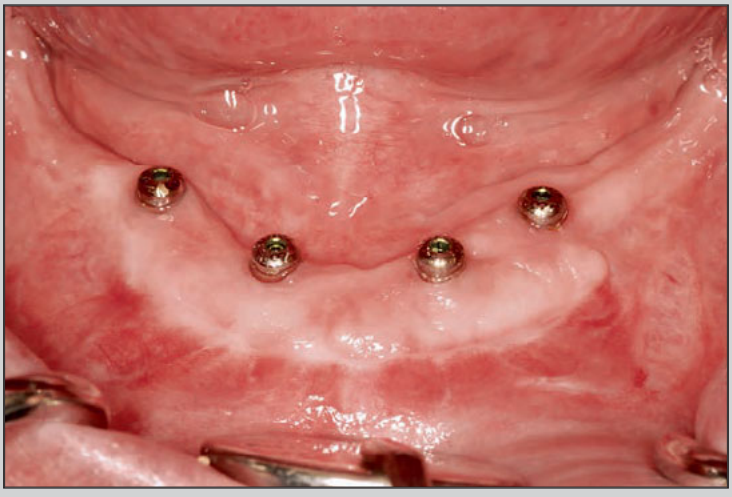
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Paradigm Shifts in the Evolution of Implant Therapy



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Making treatment decisions in dental implantology has evolved over the last five decades. These decisions and the clinical management of sites thereafter are selected based on recent changes, including the achievement of osseointegration, reestablishment of biologic width bone remodeling, the peri-implant soft tissue phenotype, the way peri-implantitis is defined, and advancements in digital technology. This article discusses these key aspects and their effects and influence on implant therapy. Int J Periodontics Restorative Dent 2022;42:605–612. doi: 10.11607/prd.6188

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Over the last five decades, making treatment decisions in dental implantology has evolved. These decisions are now partly based on the achievement of osseointegration, and they attempt to help clinicians gain a solid understanding of *(1)* the biologic behaviors of soft and hard peri-implant tissues under healthy and pathologic conditions, and *(2)* the advances in dental technology that may be used to develop more individualized treatment strategies. Subsequently, treatment options and the clinical management of sites thereafter are selected based on these recent changes, including the achievement of osseointegration, reestablishment of biologic width bone remodeling, the peri-implant soft tissue phenotype, the way peri-implantitis is defined, and advancements in digital technology. These key aspects caused paradigm shifts in the evolution of implant therapy, and their effects are discussed here.

Achievement of Osseointegration

Today, using implants for dental rehabilitation is a well-consolidated procedure with high predictability and patient satisfaction. The present state of the art is the result of decades of intense and frenetic research on the biology of osseointegration

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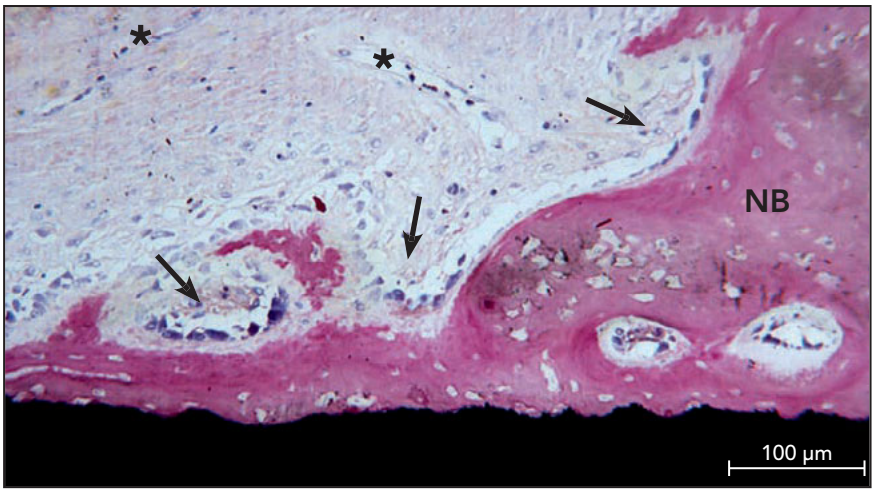


Fig 1 *Optical micrograph at 3 weeks after implant placement. Newly formed bone (NB) with wide osteocyte lacunae lines the implant surface and is in turn lined by an osteoid matrix, newly deposited by a rim of osteoblasts (arrows). In the marrow space, small and large blood vessels (asterisks) can be observed. Acid fuchsin-toluidine blue stain, ×100 magnification. Image courtesy of Prof Giovanna Iezzi and Prof Adriano Piattelli.*

and soft tissue remodeling. Early trials, from the first half of the 20th century, were affected by high failure rates and the frustration of no bone-to-implant integration. The infancy of modern implant dentistry started in the 1960s, when the pioneer P. I. Brånemark began the era of osseointegration.[1] The clinical use of osseointegrated implants was tested first in edentulous arches,[2] and the outstanding results encouraged the use of implants for partially edentulous patients in the late 1980s. Classical criteria of success for osseointegrated implants were proposed by Albrektsson et al[3] and revised by Smith and Zarb.[4] They were not the first to be published, but were the first to best express the clinical behavior of dental implants. The implant must have been immobile, without radiolucency at radiographic examination, and asymptomatic, as well as having a survival rate higher than 85% at 5 years and having early bone remodeling below 0.2 mm for each additional year.[3,4] The primary goal of these criteria was to officially set a safe and predictable starting point for osseointegration, based on implantology.

The large-scale use of rough surfaces was a spontaneous evolution for implant dentistry. The need for faster osseointegration and stronger bone-to-implant contact was followed by landmark translational research on the implant-bone interface (Fig 1). Bone healing around rough or smooth surfaces followed the same sequence of events, with coagulum and primitive connective tissue in the chamber contained between the threads, replacement of granulation tissue with provisional matrix, deposition of woven bone, and remodeling in mature bone. The notable difference between smooth (Sa: 0.35 µm) and moderately rough (Sa: 2.29 µm) surfaces was the higher bone-to-implant contact for rough surfaces and the different dynamics of bone apposition. Indeed, while bone apposition for rough surfaces was noted from both the implant surface (contact osteogenesis) and the surrounding bone marrow (distance osteogenesis), bone apposition around smooth surfaces occurred solely by distance osteogenesis.[5] Hydrophilic rough surfaces allowed faster bone deposition and upregulation of genes of osteogenesis and angiogenesis.[6] The latest advances focus on the nanoscale level to prevent biofilm-induced complications and to further improve osteogenesis.[7] Nanosurface topography preventing bacterial colonization, antimicrobials bonded to the implant surface, and active release of antimicrobials represent the cutting-edge advancements in surface-related research and open a new chapter for the prevention of infectious diseases.

Biologic Width Reestablishment and Bone Remodeling

The classical criteria of clinical success—accepting 1.5 mm of bone loss the first year[2] followed by 0.2 mm each following year[3,4]—seems outdated today. While current clinical trials and meta-analyses report early bone remodeling stably < 1 mm, intense research is ongoing to further reduce this undesirable outcome.[8]

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Proposed theories that tried to explain the phenomenon of postrestorative bone loss include the following: *(1)* microbial contamination of the implant-abutment interface that would trigger migration of inflammatory cells close to the implant platform; *(2)* abutment bending movements, with the opening of a microgap close to the bone crest; and *(3)* repeated unscrewing of the prosthetic components that would have disrupted the connective tissue seal.[9] Efforts need to be made to minimize early crestal bone resorption to reduce the risk of exposing the implant roughness to the oral cavity, prevent bacterial contamination of the implant, reduce the risk of unesthetic recessions, and avoid deep probing depths of peri-implant sulcus. Multiple strategies have been proposed to guide this process of physiologic bone remodeling, and platform switching (PS) is among the most documented.[10] Hypotheses in favor of PS were based on the inward positioning of the implant-abutment microgap, resulting in a location of the inflammatory infiltrate further from the bone crest, in addition to the effect of horizontal tissue thickening. A well-designed randomized clinical trial and meta-analysis[8] concluded that PS connections outperformed in terms of bone preservation when compared with their matching counterparts, clarifying that bone preservation was more notable for larger mismatches.

Current hypotheses acknowledge the process of reestablishing the peri-implant biologic width as the primary etiology of early bone remodeling. The peri-implant biologic width in humans has been estimated at a stable 3 mm, comprising 2 mm of epithelial attachment and 1 mm of connective tissue attachment.[11] Uncovering the implant and connecting prosthetic components would trigger a physiologic self-limiting bone remodeling that reestablishes a biologic attachment and separates the oral cavity from crestal bone. An experimental animal study,[12] a human controlled trial,[13] and a meta-analysis[14] concluded that implants surrounded by thin mucosa experience more early bone loss than implants surrounded by thick mucosa, validating the role of supracrestal tissue height in bone remodeling. Abutment height and apicocoronal positioning of crown margins are additional factors that influence peri-implant bone remodeling. In case of a short abutment with a subgingival crown margin, reestablishment of the supracrestal tissue height is guided by the position of the crown-abutment interface, regardless of the thickness of the mucosa, leading to increased marginal bone loss.[15]

An understanding of the biologic principle that bone remodeling will reestablish a minimum distance between the alveolar crest and the crown-abutment interface should guide clinical decision-making when restoring crestally and subcrestally placed implants. Accurate registration of baseline mucosal thickness and placing the crown margin at the level of the gingival margin are important considerations in order to minimize the extent of peri-implant bone remodeling.

Peri-implant Soft Tissue Phenotype

Whether a minimum band of keratinized tissue (KT) is needed to maintain peri-implant health has been largely debated. Hypotheses supporting the protective role of KT are based on the following: vestibular depth to provide comfortable toothbrushing; dissipating muscle pulls; recession prevention; and esthetic improvement. Classic studies confirmed the association between a lack of KT and mobility of the mucosal margin,[16] and higher recession was documented around implants surrounded by narrow KT,[17] but concluded that these events had no influence on peri-implant health.[16] Due to the challenge of investigating the effect of baseline KT on tissue health, one study[18] investigated whether soft tissue augmentation procedures were followed by improved clinical markers of health. The study concluded that KT increase was successful in decreasing mucosal inflammation, plaque accumulation, and bone remodeling when compared to nonaugmented sites.[18]

While research on KT aims to clarify its role for long-term maintenance of biologic health, the clinical implications of mucosal thickness and position of the mucosal margin mainly relate to esthetics (Fig 2). Apical migration of the

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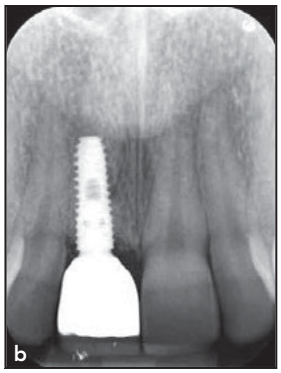


Fig 2 *Esthetic, healthy, and functional integration of natural dentition with an implant-supported restoration.* (a) *Esthetic result of the implant crowns.* (b) *Radiographic view of a single implant in the maxillary right central incisor location.*

mucosal margin is an unesthetic, undesirable event that results from a previously known or undiagnosed bone dehiscence. The current understanding of the relationship between facial bone thickness, bone height, and risk of recession is that the buccal bone integrity is related to mucosal margin stability, while bone dehiscence predisposes a site to recessions that may or may not occur. More challenging clinical scenarios, like immediate implant placement, significantly increase the risk of recession, and the severity is higher for facially placed implants. Adequate implant positioning and bone grafting reduced the risk and extent of recessions, but in one study, an average recession of 1 mm and a lack of buccal bone were noted in one third of the patients.[19] To minimize the risk of recessions after immediate implant placement, a recent investigation combined soft and hard tissue grafting[20] and documented successful results for sites receiving both interventions (0.1 mm vs 0.5 mm). Often, patients seek treatment for preexisting recessions. Burkhardt et al published the first prospective study on peri-implant coronally advanced flap with connective tissue graft and reported a mean recession coverage of 66%.[21] Despite the significant reduction in recession, the authors noted that complete coverage could not be achieved. Due to the biologic difficulties related to the manipulation of peri-implant soft tissue, more recent approaches follow a prosthetic-surgical multidisciplinary phase. For one study, this begins with crown removal, spontaneous thickening of resident soft tissue, connective tissue graft intervention, and fabrication of a new crown.[22] The reported mean root coverage was 96% at 1 year, with complete coverage in 75% of cases.

Manipulation of peri-implant soft tissue is among the most delicate tasks of periodontology. The need for keratinized tissue is an active debate, and future investigations will clarify the different contributions of the whole keratinized tissue and the attached tissue. Regarding peri-implant recessions, preventive measures with phenotype augmentation procedures and corrective interventions with soft tissue grafts have been documented. The goal of the next generation of investigations will be to clarify the external reproducibility of coverage procedures and to investigate the case selection for collagen substitute materials.

Definition and Treatment of Peri-implantitis

Peri-implantitis is a chronic infectious disease of soft and hard peri-implant tissues.[23] The case definition of peri-implantitis has changed multiple times over the years, and each change had strong implications on the epidemiology and demographics of clinical trials (Fig 3). As reported, a 47% prevalence rate of peri-implantitis occurred with any bone loss larger than 0.5 mm, while it was only 1% for diagnostic criteria of bone loss more severe than 5 mm.[24] The VIII European Workshop: Clinical Research on Peri-Implant Diseases was landmark in officially setting the diagnostic cutoff as 2 mm of bone loss.[25] The proposed definition was widely accepted by the research community and was adopted in the clinical

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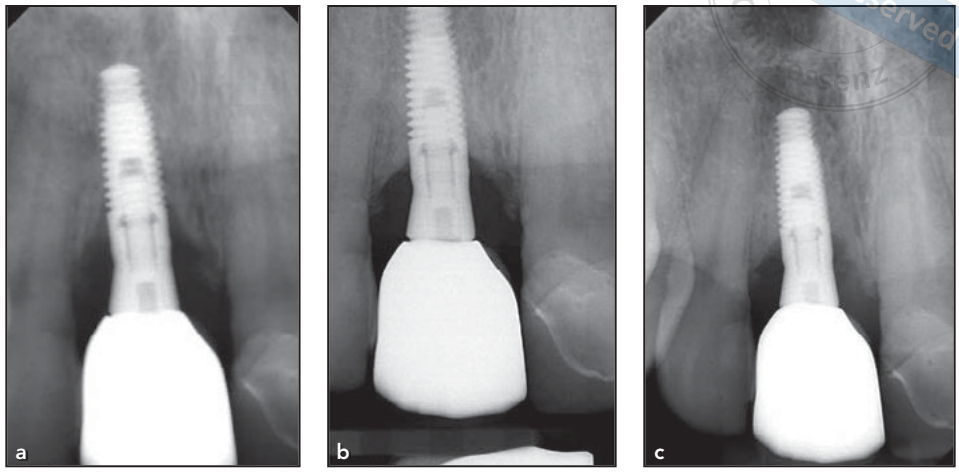


Fig 3 *Radiographic diagnosis and follow-up of peri-implantitis at the maxillary right central incisor location.* (a) *Intraoral radiographic evaluation revealed a deep narrow infrabony defect involving the coronal third of the implant. The implant was treated with open flap debridement.* (b) *One year after the intervention, stability of crestal bone was achieved with remineralization of the apical aspect of the defect site.* (c) *The stability of crestal bone levels was maintained 18 months after intervention.*

trials performed in the last decade; the reported peri-implantitis prevalence was approximately 15% using 2 mm of bone loss as a diagnostic criteria.[26] The latest official definition of peri-implantitis was provided during the 2017 World Workshop, which changed the criteria to 3 mm of bone loss together with a 6-mm pathologic pocket depth and inflammation.[23]

The case definition of peri-implantitis is strongly related with a successful or failing outcome after treatment. "Survival" refers to the retention of the implant in the patient's mouth with maintenance of osseointegration, and it does not include biologic parameters like bone levels, probing depth, or presence of inflammation. Regarding implant "success," heterogeneous interpretations exist, ranging from the sole stability of bone levels to the composite criteria matching bone preservation with a shallow pocket and no inflammation. The evaluation of success is further complicated by the interoperator variability related to peri-implant clinical measurements.[27] Systematic reviews on long-term survival after treatment of peri-implantitis documented a progressive drop with time, representing a call for a more careful investigation of factors affecting treatment outcomes.[28] Nonsurgical debridement of the implant surface was shown to be ineffective due to the limited access. Despite the proposal for new devices for improved plaque control,[29] dedicated home care and nonsurgical instrumentation are not enough to reverse peri-implantitis, and they currently represent a preparatory step followed by corrective surgical intervention. Surgical access has been combined with multiple mechanical devices and/or disinfectant agents in an attempt to completely remove the pathogenic biofilm[28,30–32] and modulate the inflammatory response.[33] Suprabony defects in implants with nonmodified surfaces responded to resective protocols with favorable outcomes, while rough surfaces surrounded by infrabony defects were best approached with reconstructive protocols.[28] The latest research acknowledges the crucial role of risk assessment and prevention at the individual level; newly proposed was the IDRA (implant disease risk assessment) diagram that combined systemic susceptibility, prosthetic factors, and local biologic factors for a personalized risk-assessment evaluation.[34]

Current knowledge on peri-implantitis is based on critical appraisal of data acquired using previous, more permissive criteria, and as of yet, there are few data from clinical trials testing the clinical implications of the new case definition. Following the trend of personalized medicine, future research will focus on the development of algorithms for personalized risk assessment and prevention of peri-implant diseases.

Advancements in Digital Technology

Clinical use of oral implants began much earlier than digital planning and computed tomography. Planning was based on casts and

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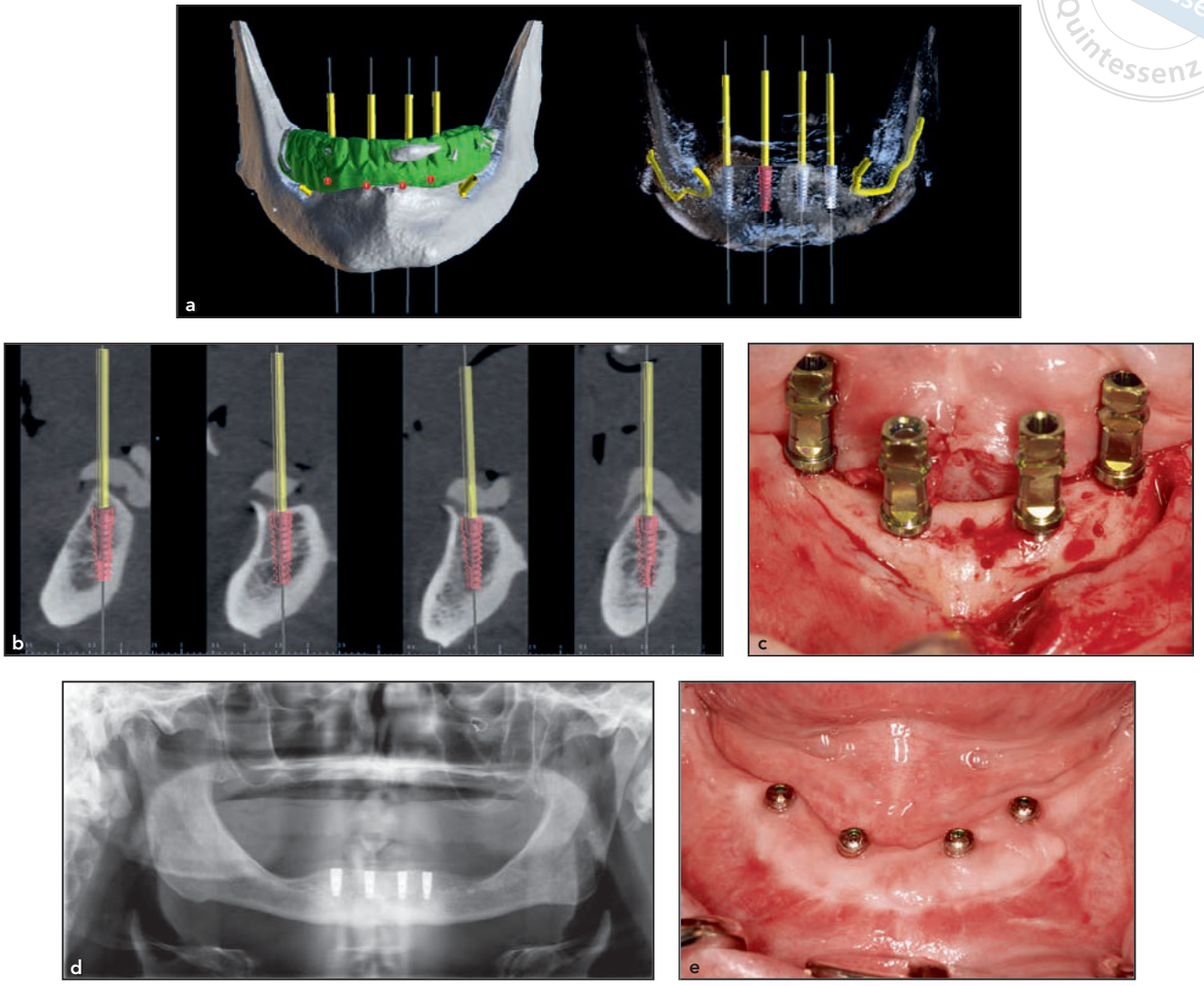


Fig 4 *Digital workflow and placement of four mandibular implants.* (a) *Implant planning was performed by superimposition of the CBCT scan with the prosthesis surface scan.* (b) *Cross-sectional view of the digital implant positioning.* (c) *Implant placement.* (d) *Postoperative panoramic radiograph.* (e) *Clinical view at the 4-month follow-up. Clearance was obtained for restorative phases.*

panoramic and intraoral radiographs at first. Digital technology was then implemented to investigate anatomical structures including, but not limited to, ridge volume, inferior alveolar canal, mandibular lingual undercut, maxillary sinuses, septa, and vascular anastomosis. During the last decade, applications of digital technology gradually moved from diagnosis to therapy, making digital planning and guide-printing routine phases of clinical practice.

The digital workflow for guided surgery usually refers to a sequence of phases, as follows: *(1)* data acquisition through CBCT and a surface scanner, *(2)* superimposition of hard and soft tissue data, *(3)* virtual implant placement, *(4)* designing and printing a guide, and *(5)* finalizing the plan with guided drilling and implant placement[35] (Fig 4). Despite some clinical limitations of the printed guide (such as reduced visibility and difficult access to posterior areas), guided surgery was largely accepted by practitioners for its high accuracy and the potential for reduced surgical time. The need for guided surgery became more evident for challenging clinical scenarios. In a cadaver study investigating immediately placed implants, anatomical complications such as

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incisor nerve canal invasion and buccal fenestration were reported three times more frequently for free-hand implants than for partially guided ones.[36] In addition, the inaccuracy with the plan was higher for the free-hand group, with coronal deviation of 1.4 mm compared to 0.8 mm for the guided surgery, an apical deviation of 2 mm vs 1 mm, and angular deviation of 6 degrees vs 3 degrees. Currently, digital workflow is also used in bone regeneration, especially when using customized CAD/CAM titanium mesh.[37]

Similar to the studies that aim to test and improve printed guides, virtual dynamic navigation evolved from neurosurgery and has been immediately adopted by other surgical medical specialties thanks to its great advantages in terms of precision, minimal invasion, and short surgical times.[35] The "navigation" part of dynamic navigation is derived from the surgeon's ability to see a virtual model of the patient and instruments moving in real time on the screen, while "dynamic" refers to the motion-tracking technology (as opposed to the "static" computer-assisted surgery of printed guides). The literature is optimistic about the future use of real-time navigation in oral implantology. Navigation was used to increase predictability and reduce complications during advanced surgeries like zygomatic implants[38] and has been tested for routine dental implantology with favorable results.

Technology has been one of the most irreplaceable contributions toward the development of modern dental implantology. Its use for diagnostics and planning shifted the paradigm from experience-oriented treatments to carefully checked digital plans. State-of-the-art technology supports the routine use of static computer-assisted guides for implant placement and acknowledges its superiority for accuracy and shortened surgical times compared to traditional protocols. Future technological advancements will further improve the accuracy of static-guided surgery, overcome the visual and accessibility challenges, and will experiment with the effectiveness of dynamic navigation for day-to-day clinical settings.

Conclusions

As highlighted above, implant dentistry is an actively evolving discipline that has achieved osseointegration and built upon that to include tissue remodeling. Starting with the physiology of healthy hard and soft tissues, implant dentistry considers the various peri-implant pathologies and explores the possibilities of digital technology to define and renew the criteria of successful implantology. All of these aspects work symbiotically to reflect the robust benefits promoted by implant-based procedures and the subsequent potential for successful case management.

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