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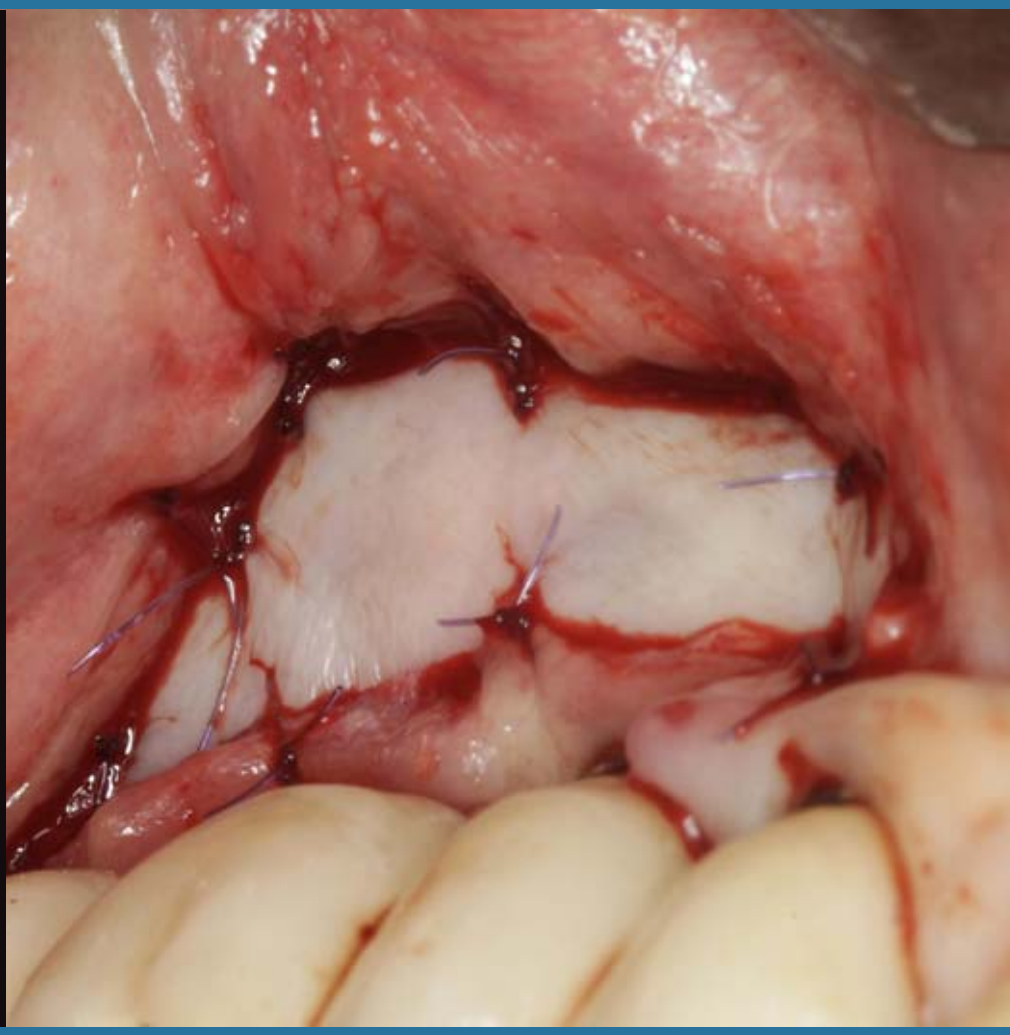
Implant planning and surgical aspects to reduce the risk of peri-implantitis

Patient-related risk factors for peri-implantitis and pre-implant treatment



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Title picture: From original article by Keeve: Patient-specific treatment of peri-implant inflammation, pp. 18–29. Figure 9: Harvesting of free mucosal graft (right palate) and vestibuloplasty in order to widen the keratinized mucosa. (Photo: P. Keeve)
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Norbert Enkling

Osseoperception: tactile sensibility of dental implants?

Teeth as sensory instruments

"Teeth as sensory instruments" was the title given by Münch and Schriever as early as 1931 in keeping with the tradition of Peaslee (1857) and Sigmund (1867), who were already aware of the fine tactile sensibility of teeth (quoted from Utz, 1982 [65]). The complex stomatognathic system has a built-in protective reflex that produces an unpleasant sensation when biting on a hard object; which leads to reflexive mouth opening and thus reduces damaging influences on the system [76]. Besides the functions that teeth fulfill during speech, food intake and food processing, they also play an esthetic role and are involved in the neural reflex control circuit of the stomatognathic system: teeth serve to sense foreign bodies and to ensure the jaw posture [65].

The types of spatial perception via the teeth have been investigated in several studies [75]:

- the perception of interocclusal test objects = active tactile sensibility
- the perception of axial and/or horizontal contacts of the teeth = passive tactile sensibility = sensation of pressure
- the ability to discriminate interocclusal thicknesses = discrimination ability
- the ability to recognize shapes in the oral cavity or to distinguish between two points of contact (stereognosis).

Jacobs emphasized that passive tactile sensibility can only perceive stimuli from single neural receptors, whereas active tactile sensibility represents normal function and involves all types of receptors such as muscle, joint, or tegument receptors [23].

Therefore, when examining the sensibility of the tooth as part of a control mechanism, it makes sense to use active tactile sensibility.

The active tactile sensibility of natural teeth varies greatly between individuals: in the study performed by Utz, natural teeth had a median tactile sensibility of approximately 15–30 µm, with the exception of canine teeth, which had a tactile sensitivity of 60 µm. However, the interindividual values varied between 2 µm and 425 µm [65, 66]. In more recent studies, the absolute values of tactile sensibility of natural teeth varied between 2 µm and 77 µm with a mean value of 17 µm for different individuals [14]. The influence of gender on tactile sensibility is small at best [61]: Most authors could not determine any correlation [4, 14, 65]. However, there appears to be a correlation between tactile sensibility and age: with increasing age, tactile sensibility decreases [18]. The mean increase in the interocclusal tactile threshold is circa 2.2 µm for every ten years of age. Moreover, subjects with increased individual tactile sensibility threshold values show greater tactile sensation uncertainty [14].

Osseoperception

Studies on osseointegrated orthopedic prostheses after the amputation of arms or legs have shown that such treatments resulted in a return of sensation due to mechanical stimulation [10, 34]. This recovery of somatosensory control circuits permits a more natural use of dentures and reduces the risk of denture and implant overloading [24]. Patients were able to discriminate between different mechanical stimuli acting on the osseointegrated prostheses [10, 56]. This ability was greater by 27 % compared to patients with conventional tubular prostheses [24]. An activation of receptors in the bone, periosteum, joint capsule or other tissues is assumed to be the cause of the stronger sensitivity [29].

Today, missing teeth can be replaced with alloplastic implants with a high probability of survival. Such restorations come close to a "restitutio ad integrum" [38]. However, the question regarding the extent to which dental implants are integrated into the existing stomatognathic control circuit remains unanswered [2]: does the "implant as a foreign body" need to be protected in a special way [31], or can it be considered a "fully fledged replacement tooth" with its own sensory perception [60]? Early on, Mühlbradt et al. discovered that sensory information can also be transmitted by dental implants [45, 46]. The ability of allo-

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plastic, and thus, non-vital, ankylotic-anchored titanium implants to develop some degree of tactile sensibility has been the subject of numerous publications in the past two decades. Brånemark coined the term "osseoperception" for them [5, 6, 41].

Physiology of dental sensory perception

Proprioceptors and exteroceptors are responsible for the tactile sensibility of teeth: proprioceptors, such as muscle spindles and joint receptors, are activated by stimuli from within the body and provide information about the relative position and movement of the body's parts. They are distinguished from exteroceptors, which are stimulated by external stimuli and are located in the skin, mucosa, periosteum, bone, gingiva, and periodontal ligament. Exteroceptors provide information to the central nervous system about external loads and play an important role in tactile sensibility [23].

Depending on mouth opening, both proprioceptors and exteroceptors play a role in the interocclusal tactile sensibility of natural teeth: during wide mouth opening, interocclusal tactile sensibility can be attributed primarily to the muscle spindles and joint receptors of the temporomandibular joint [8, 9, 33].

With less interocclusal distance, i.e. with smaller thicknesses of the interposed foreign bodies, the tactile sensitivity becomes finer and is determined by the exteroceptors [26, 71]. These mechanoreceptors are located in the gingiva, the alveolar mucosa, and above all in the periodontal ligament, which in turn already reacts to low forces applied on the teeth. Van Steenberghe found that the functional properties of periodontal receptors are comparable to those of receptors found in the rest of the body skin [71]. Subsequently, the assumption that nerve endings of the dental pulp might be involved in tactile sensibility in addition to nociception could not be corroborated [35]. Endodontically treated teeth exhibit the same tactile sensibility as vital teeth [65].

The recorded EMG reflex responses are reduced by approx. 90% under local anaesthesia of the examined tooth [69]. This led to the conclusion that the periodontal mechanoreceptors have a dominant function; the joint and muscle receptors therefore only play a subordinate role [43, 72]. However, the finding that a compromised periodontium following periodontitis does not lead to a reduction in tactile sensibility brings into question the dominant role of the periodontium [39]. The neurophysiological receptor apparatus, which is activated when a tooth undergoes intrusion in its alveolar socket as a result of occlusal load, is absent for implants (Figs. 1 and 2).

Figure 1 Schematic representation of a cross-section through a natural tooth together with periodontal tissue.

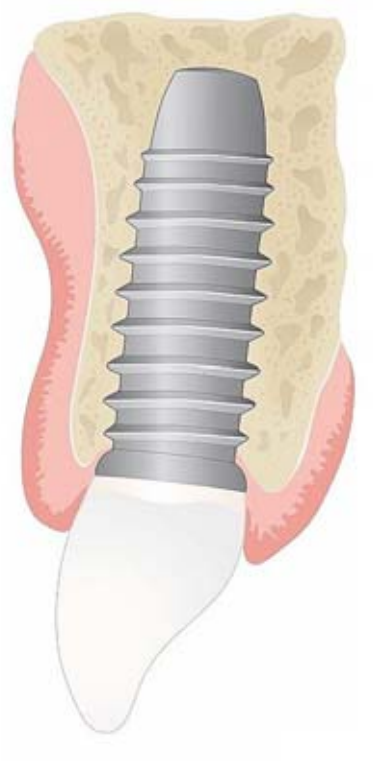

Figure 2 Schematic representation of a cross-section through an osseointegrated implant together with peri-implant hard and soft tissue.

The physiological mobility of teeth differs from that of implants. Tooth movement can be divided into two phases: in the first phase, under minor loading of the tooth, tooth mobility is determined and/or constrained by the fibers of the desmodont. In the second phase of movement, with increased loading, the bone undergoes elastic deformation as soon as the capacity of the desmodont is exhausted [32, 48, 60]. The mobility of an osseointegrated implant is entirely attributable to the elastic deformation of the bone under both horizontal and axial loading, and it can reach only one tenth of the mobility of natural teeth [52, 59]. However, Richter reconstructed a different behavior of natural teeth: the hydraulic system of the periodontium is only subjected to very short-term forces under physiological loads, e.g. during speech and chewing; tissue fluid cannot be displaced from the periodontal gap because this would require forces acting for a longer period of time. So, with normal function, natural teeth behave very similarly to implants in their movement pattern. The large intrusion capacity of the teeth is only exhausted in the case of parafunctions [54].

Methods to examine tactile sensibility

In principle, there are two different approaches to determine the stimulus threshold values of receptors [23]:

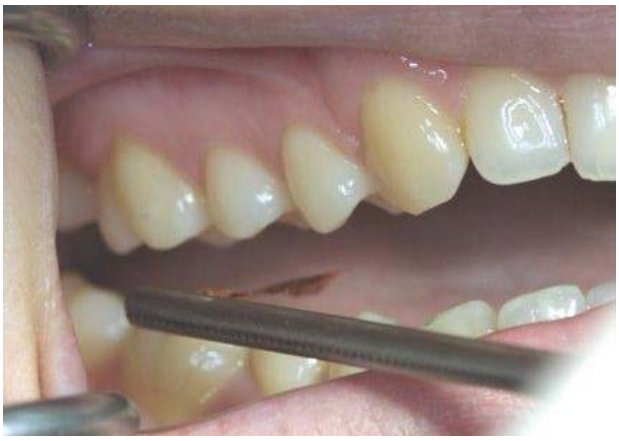

Figure 3a Experimental procedure for interocclusal tactile sensibility/active tactile sensibility: cheek retractors are used to retract the corners of the mouth and a test foil is inserted in the interocclusal space.

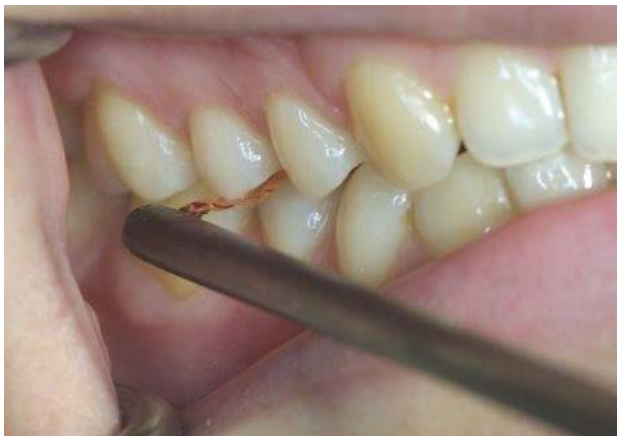

Figure 3b Test position: after the investigator's request, teeth clenching is performed by the subject.

1. the neurophysiological examination method and
2. the psychophysical examination method

In the neurophysiological examination method, an objective evaluation of the stimulus response of the receptors can be carried out invasively via microelectrodes and non-invasively via a recording of somatosensory evoked potentials. Alternatively, functional magnetic resonance imaging (fMRI) can be used to record changes in the brain when the tooth/implant is stimulated [36].

In the psychophysical examination method, the acting stimulus is compared to the subjective sensation of the test subject. If carefully applied in a standardised experimental setup, the psychophysical methodology can be used to establish a correlation between physiological functions of receptors and subjective responses of subjects in the context of an investigation of receptor sensitivity threshold, and it provides equally valid results compared to the more invasive, neurophysiological investigation methods. The psychophysical method can also be applied to larger sample populations than the neurophysiological method, and thus, it leads to more valid statements [68].

In the active tactile sensibility test, subjects are asked to bite on interocclusal foreign bodies of varying thickness. So-called "blank trials" (mock trials) are included in the test in order to check the statements of subjects (Figs. 3a, 3b). The test can thus come to the following results:

true positive = presence of a foreign body was correctly detected by the subject

true negative = absence of a foreign body was correctly detected

false positive = despite the absence of a foreign body, one was reported as being present

false negative = a presence of a foreign body was not detected

The 50 % value (proportion of correct answers = 50 %) has become established as the definition of tactile sensibility [64]. Since this 50 % value can be achieved with several foreign body thicknesses, the interpolated 50 % value is specified [26] (cf. Fig. 4). Recent literature recommends an evaluation by means of a logistic regression or – even more precisely – using an asymmetric Weibull distribution as an approximation to the tactile sensibility curve. This model has the advantage that, in addition to the 50 % value, it can also determine the support area (10 % to 90 % interval), or the slope of the curve at the 50 % value, as a measure of the individual certainty of the statements: a steep curve or small interval indicates high certainty, while a shallow slope or large interval indicates lower certainty/higher uncertainty when sensing foreign bodies [13, 14].

The thickness of the thinnest color of articulating film (thickness of 8 µm) in common use has been established as a measure for defining an equivalent tactile sensibility (± 0.008 mm) [15].

Results on the tactile sensibility of implants

Active tactile sensibility is ten times poorer for complete dentures compared to natural teeth [67]. The tactile sensibility of implants, on the other hand, is similar to that of natural teeth [16, 51]. However, stereognosis remains better with natural teeth than with implant-supported restorations [4]. Edentulous patients with fixed, ceramic-veneered implant-supported restorations in the maxilla and mandible sometimes describe their bite as feeling very hard, like "biting on granite" [37]. Active tactile sensibility of dental implants is described by subjects as being rather dull and less localized compared to that of natural teeth [47].

In the passive tests, osseointegrated implants showed no pressure sensibility at very low static loads, but clear sensibility at stronger static and dynamic (= vibrations) loads (axial and horizontal). Maxillary implants showed higher stimulus thresholds compared to implants in the mandible. This can be attributed to the involvement of muscle,

tendon and joint receptors during stimulus initiation at mandibular implants [78].

In the case of active tactile sensibility, which corresponds most closely to natural function, it was shown that the tactile sensibility is the same between single-tooth implants and natural contralateral teeth in intraindividual comparisons [15]. Even under anaesthesia of the natural antagonists of the implant and of the contralateral tooth the tactile sensibility is still very fine and intraindividually equivalent between implant and tooth [13].

However, the active tactile sensitivity of implants differs between individuals and varies between 2 µm and 54 µm with a mean value of 21 µm [15]. The slope of the tactile sensibility curves of implants is flatter than that of control teeth in intraindividual comparisons. This means that the tactile sensibility of implants is slightly less reliable than that of natural teeth [16].

The implant surface and implant geometry, i.e. implant length and thickness, and thus, the size of the bony attachment around the implant, have no effect on tactile sensibility. Likewise, gender and age have no effect [15, 16]. With regard to the dependence of tactile sensibility on age, Wedig [75] was the first to differentiate between implants and natural teeth: for natural teeth, the tactile sensibility thresholds increase the older the subjects are. Conversely, in the case of implants, there is no correlation between tactile sensibility and age. The interocclusal tactile sensibility of implants corresponds to that of teeth in older subjects [15].

The difference between active and passive tactile sensibility of implants is explained by the fact that active tests stimulate different receptor groups, whereas the passive method is designed to selectively target receptors in the periodontal ligament, which are absent in the implant region following tooth extraction [25]. The forces that occur under function, e.g. when chewing on the implants, are significantly higher than the lower forces that could be determined as threshold values in passive tactile sensitivity tests. [40].

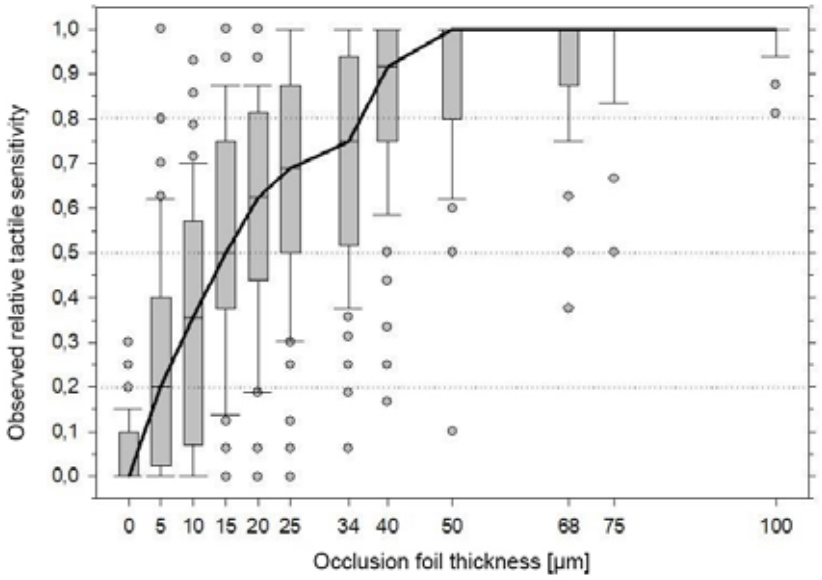

Figure 4 Representation of the results of a sample on the active tactile sensibility of implants. The 50 % value of correct results is defined as the threshold value of tactile sensibility. The 50 % threshold is reached using 15 µm occlusion foil.

For fixed restorations, active tactile sensation was slightly poorer when two implants occluded against each other than when one implant functioned against a natural tooth [1]. Some authors describe that there is a noticeable improvement in tactile sensibility as the implant's functional life increases [1, 40, 44]; however, other studies which used vibration tests did not find these differences [24]. Thus, there seems to be a phase of individual adaptation when it comes to tactile sensibility, which is also known from extensive prosthetic treatments [36, 40, 50].

Explanatory approaches to the physiology of tactile sensation with implants

The physiological basis for the tactile sensibility of osseointegrated implants, summarized under the term "osseoperception", has not yet been definitely clarified. In principle, two different theories exist:

Theory 1: activation of receptors found in local bone

Theory 2: activation of more distant receptors

Theory 1: The involvement of bone innervation in mechanical sensations remains disputed [20]. The function of bone innervation may be limited to only vasoregulatory and bone remodeling processes. Most nerve fibers have free nerve endings in bone which are connected to the endosteum, blood vessels or connective tissue components. These free nerve endings may also be able to respond to pressure and pain stimulation. Sisask et al. found a high density of neuropeptides in bone marrow [62]. Experiments on dogs have demonstrated that implant materials are abundantly surrounded by nerve fibers in the region of the implant-bone interface [21, 74]. Similarly, numerous unmyelinated and myelinated nerve fibers have been found on explanted dental implants from humans [11]. It was found that more nerve fibers were present at the peri-implant bone site than in the rest of the edentulous jaw region [20]. Immediate implant placement and immediate loading seem to result in increased nerve attachment at the implant site in comparison with concepts of delayed implantation [21]. This has given rise to the hypothesis that nerves originate from the periodontal remnants of extracted teeth, thus implying, that lower tactile sensibility of implants is to be expected after a longer post-extraction period [74]. However, the postulated re-

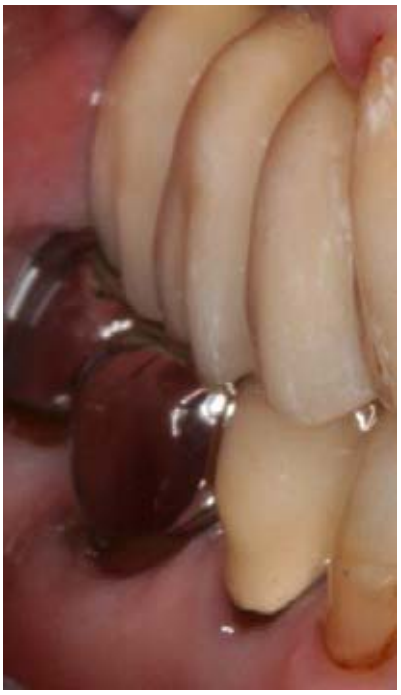

Figure 5a Clinical example showing the relationship between occlusion and ceramic chipping. Initial situation: cusp-to-cusp occlusion at implant crown 16 and tooth crown 46.

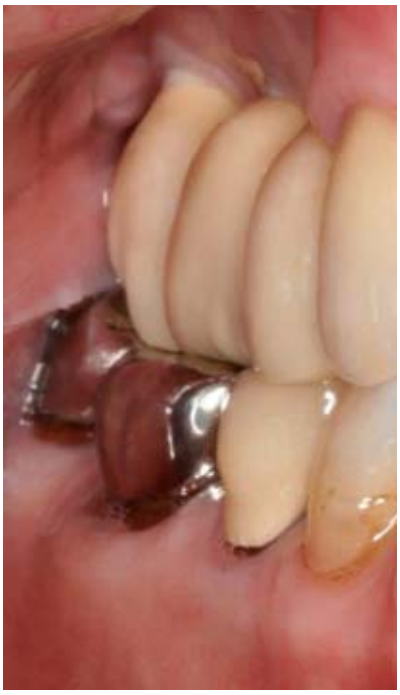

Figure 5b Buccal view of the situation after the chipping of the ceramic veneering at the tip of the mesiobuccal cusp of 16.

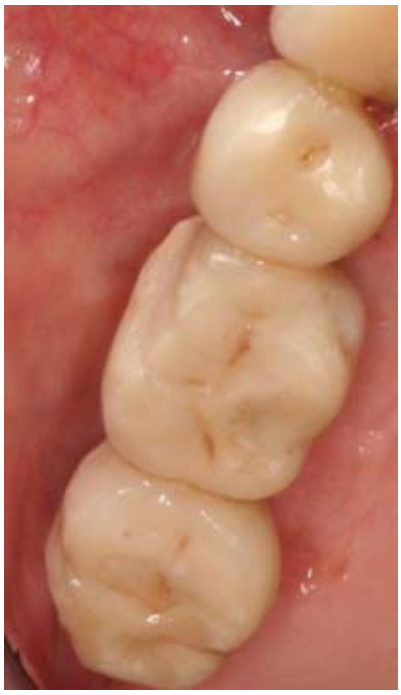

Figure 5c Occlusal view of the situation after the chipping of the ceramic veneering at the tip of the mesiobuccal cusp of 16.

Fig. 1–5: Norbert Enkling

lation of tactile sensibility to the time interval between tooth extraction and implant placement could not be confirmed in recent studies [16]. The remaining periodontal nerve structures do not appear to have any relevance with respect to tactile sensibility at the implant sites in the end. This is because implants placed in iliac crest grafts, in which periodontal structures could not be present, achieved results equivalent to those of implants in the local bone [49].

When passive tactile sensibility was tested with and without local infiltration anesthesia of the peri-implant tissue in the presence of an unscrewed abutment, so as to exclude any possible contact with the soft tissue, no effect on the sensibility threshold values during static and dynamic loading of the implants was recorded. Moreover, the tactile sensibility of natural teeth was significantly poorer under soft tissue anesthesia. This means that the anesthesia switched off peri-implant receptors of the gingiva, mucosa and periosteum, and consequently, the unchanged tactile sensibility indicates a response of more distant receptors. In the case of static loading, the results indicate that anesthetized teeth and implants reach approximately the same values, namely about 6 Ncm [78]. Using a neurophysiological test set-up in humans, in which the implants were electrically stimulated, an electroencephalogram (EEG) clearly revealed a response in the brain, which could not be reduced even by surface anesthesia of the peri-implant mucosa. The peri-implant mucosa therefore appears to play no or only a subordinate role in the phenomenon of osseoperception [70]. In the case of single-tooth implants, periodontal structures of the natural antagonists and of the natural adjacent teeth probably contribute to the tactile ability: in an animal experiment, Bonte et al. found that touching osseointegrated implants resulted in a trigeminal reflex response which was dependent on the presence of residual teeth. They concluded that the origin of the inhibitory reflexes of the masticatory muscles after implant loading could be attributed to the activation of the periodontal receptors of the adjacent residual teeth [3, 63]. The relevance of periodontal receptors of natural antagonists which are involved in osseoperception is again questioned by other study results: In comparing the active tactile sensibility of single-tooth implants with that of natural teeth on the contralateral side, the anesthesia of the natural antagonists resulted in an equivalent tactile sensibility of the of the implant-side and the contralateral natural-tooth side [13].

Theory 2: Jacobs et al. assume that the cause of osseoperception are responses from more distant proprioceptors and exteroreceptors, which are evoked via activation of the bone [23].

The subjective pressure sensation of implants appears to be less accurately localized compared to that of natural teeth in passive tactile sensibility testing and it is perceived by subjects as being transmitted further into the skull. Thus, Schulte's research group from Tübingen attributed the tactile capacity of ankylosed implants to a deformation of the peri-implant bone and an associated expansion of the periosteum [60].

The transmission of mechanical stimuli can occur due to a shift of interstitial fluid in the fine tubules and lacunae of the cancellous bone, in addition to deformation of the bone [7]. The periosteum is highly innervated and substance P, which is thought to be responsible for pain sensation to a certain degree, is present in large quantities in the periosteum [73]. The periosteum contains many free nerve endings that are important for the transmission of pain, as well as Golgi-Mazzonic corpuscles that respond to pressure sensations [58]. The periosteum of the facial bone contains mechanoreceptors that respond to pressure and expansion of the periosteum, masticatory muscles, and skin [57]. In addition, the tendon and muscle spindles [55] as well as those receptors in the temporomandibular joint that correspond to the Pacini type must also be taken into account for the tactile sensibility.

In summary, the very fine active tactile sensibility of dental implants is probably due to the activation of muscle and tendon spindles and receptors in the adjacent periosteum [2]. The phenomenon of osseoperception could be traced in neurophysiological studies using fMRI: passive loading of teeth and implants were compared at 1 Hz. After tooth extraction and implant placement, a plastic change appeared to take place in the brain: stimuli at the implant site resulted in the activation of both the primary and secondary somatosensory cortex areas [19, 77].

Clinical relevance

For the clinically practicing dentist, the measure of active tactile sensibility is more relevant than the measure of passive tactile sensibility; in practice, it is easier to work with data in "mm" than with force data in "N" [65]. Premature occlusal contacts and the associated implant overloading are discussed as possible causes for implant failures [12, 22, 30, 31]. Occlusal pre-contacts of approximately 100 µm or more can result in a clinically damaging loading effect according to the studies of Falk et al. [17] and Richter [53]. Yet, this negative effect of occlusal pre-contacts on the osseointegration of implants is disputed in other studies: Miyata et al. found no negative effects on bone with artificially placed interferences of up to 250 µm in an implant trial on monkeys [42].

However, under peak occlusal loads, static and dynamic premature occlusal contacts may exceed the mechanical properties of the veneering ceramic, and thus, favor the chipping of the ceramic veneering (cf. Figs. 5a–c). In order to detect these pre-contacts, occlusal paper or foil can be employed for staining purposes. Yet, the staining of premature occlusal contacts and the interpretation of the staining marks is nontrivial, as it is difficult to stain occlusal contacts, especially on smooth ceramic surfaces [76]. Moreover, the intensity of occlusal contact staining does not necessarily correlate with the strength or force of the occlusal contact. Very strong contacts do not stain, but rather scatter the color pigments to the periphery of the contact zone [28].

Since the interocclusal tactile sensibility of natural teeth and implants is very fine, and in part even finer than that of the thinnest occlusal foil (8 µm), it seems advisable to ask patients if they are comfortable with the restoration during the try-in appointment; more specifically, this means asking them about their subjective feeling of whether or not the restoration has the correct height [27]. The interocclusal tactile sensibility of teeth and implants, i.e. the osseoperception, thus indicates the degree to which the occlusal surfaces of teeth and restorations should be ground, so that no more occlusal interferences are sensed by the patient. According to the present study, this requires a level of accuracy down to well below 100 µm.

Conflict of interest

In the past, Prof. Dr. Norbert Enkling has given paid lectures at scientific conferences and lectures with workshops for implant companies such as Nobel Biocare, SIC Invent, Dentaurum Implants, 3M Espe and Condent.

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Photo: Norbert Enkling

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The prosthetic superstructure as a risk factor for peri-implantitis

Abstract: Peri-implantitis is a plaque-associated pathological disease occurring in tissues surrounding dental implants. It is characterized by an inflamed peri-implant mucosa and resulting progressive loss of peri-implant supporting bone [8]. Prosthodontic etiologic factors such as hygiene-incompetent prosthetic designs or residual cement seem to favor the development of peri-implantitis [43]. During the course of the article, several characteristics of prosthetic superstructures are presented and their relevance in relation to peri-implant inflammation is discussed.

Keywords: implants; peri-implantitis; prosthetic; superstructure

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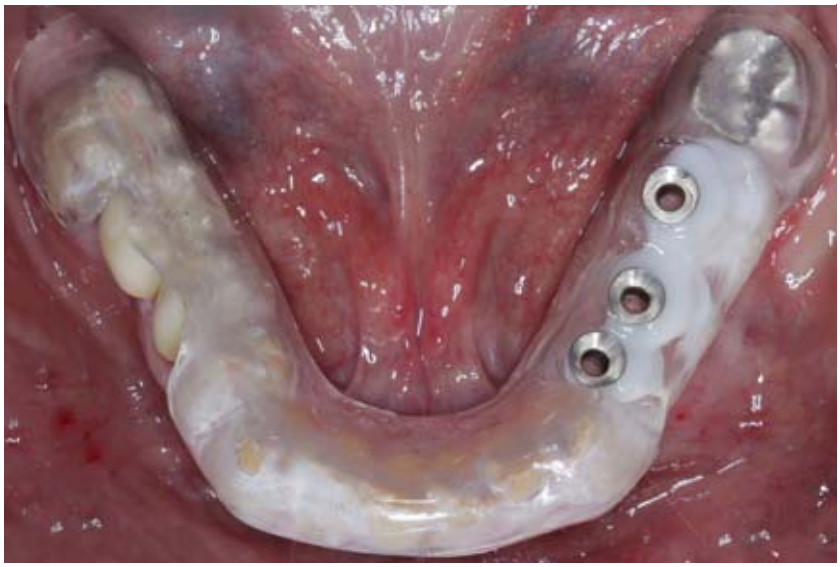


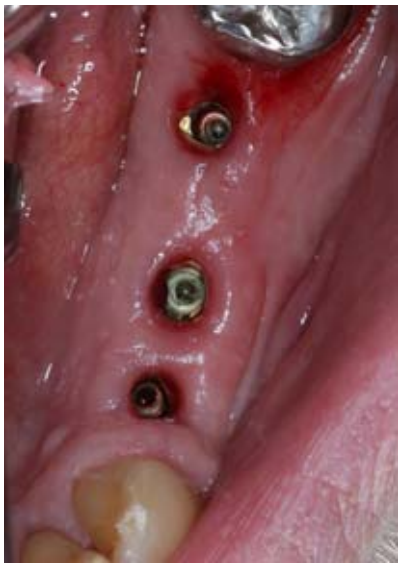


Figure 1 This case study shows the restoration of an interdental gap situation in region 34–36 using implant-supported single-tooth crowns. A dental hygiene design in the molar region was selected using an alternative crown design with a cleaning channel. The implant placement was partially guided by a drilling template.
a) Incorporated drilling template with visible sleeves region 34, 35, 36. Taking into account the minimum distances between implants and teeth, the prospective implant position 36 was planned to be further distally.
b) Clinical situation of inserted implants 34, 35 and 36 before impression taking. The more distally selected position of 36 is visible.

Introduction

The fifth German Oral Health Study indicates that the 35- to 44-year-old German population is already missing an average of 2.1 teeth [25]. The most common causes of tooth loss include caries and periodontitis. Only a small proportion of teeth are lost due to trauma. Dental implants make it possible to close gaps without drilling healthy teeth. Endosseous dental implants achieve survival rates of approximately 96% after 10 years [22]. The long-term prognosis can be strongly compromised by the development of peri-implantitis. Systematic reviews show a wide prevalence range of peri-implantitis from 1–47% [13]. Meta-analyses calculated mean peri-implantitis prevalences of 22% [13] and mean implant- and subject-based peri-implantitis prevalences of 9–20% [30]. To prevent peri-implant complications, the dental prosthesis must be designed in such a way that optimal cleaning of the scarred, defense-weak peri-implant tissue is possible. Implant planning is the basis for this. In contrast to the periodontal ligament, where the dentogingival and dentoalveolar collagen fiber bundles radiate from the root cementum in lateral, coronal and apical directions, the collagen fiber bundles on the implant are oriented from the periosteum parallel to the implant surface. In addition, the connective tissue in the supracrestal region contains more collagen fibers but fewer fibroblasts and vascular structures.

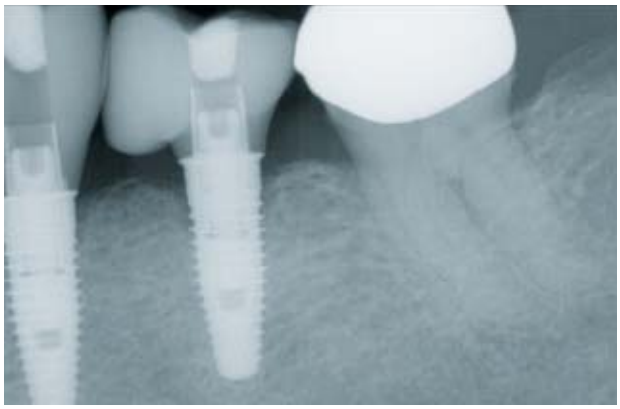
Implant planning

In terms of backward-oriented treatment planning, the starting point is a previously defined prosthetic goal. The ideal design of the prosthesis, simulated for example by an idealized wax-up/set-up, determines a favorable prospective implant position. The vertical height to the antagonist or the implant angulation can be used to assess in advance whether an implant-supported prosthesis will be anchored in a fixed position (screw-retained or cemented) or must be splinted, or whether a removable solution should be aimed for. Furthermore, it can be assessed to what extent it is possible to maintain the biological width with a distance of 2–3 mm from the rough implant surface, which is at bone level, and the superstructure and its effect on the esthetic appearance [42]. Additionally, it should be determined whether additional interventions are required to optimize the hard and soft tissue bearing in order to make the necessary compromise between ideal cleanability, esthetics and mechanical loading as beneficial as possible.

Implant system

The number of available implant systems on the market has become confusing. Studies have shown that there is a relevant correlation between the risk of developing peri-implantitis and the used system [12, 19]. Design features could play a role. For example, the height of the implant shoulder, i.e., its position at bone or soft tissue level, is discussed. The configuration of the interface is also being considered. Despite the great precision of dental implantology, bacterial colonization occurs inside dental implants [36]. The penetration path of bacterial colonization occurs via microgaps between the implant and the superstructure as well as screw channels. This implant-internal microflora is inaccessible to oral hygiene products. It has been shown that implants with tapered internal connections can reduce the micro-

c) Fabricated denture on model with occlusal screw accesses.



d) Radiographic view of implant restoration 36 after insertion. The slender emergence profile in combination with a mesially cantilevered pontic can be seen. The creation of a cleaning channel by the concave mesial emergence profile in combination with the cantilever pontic enables targeted cleaning.

gaps at the transition from implant to superstructure and reduce bacterial penetration [5, 7, 14, 28, 45]. However, to date, there is no evidence for the clinical significance of this aspect. The recommendation can be made to prefer systems with a good clinical study situation, regardless of the implant design.

Hygiene maintenance

Prosthetic rehabilitation concepts should allow complete plaque control and 360° cleanability of the peri-implant area. To achieve this, the design of the prosthesis must ensure accessibility for oral hygiene items. In addition to the toothbrush, interdental space brushes and Superfloss can be considered. Inaccessible areas should be avoided and guide functions for cleaning instruments such as interdental brushes should be designed. For all types of implant-supported restorations it is important to ensure that the patient can perform the cleaning independently. Home care and professional follow-up are crucial for the long-term success of dental implants [41]. It is advisable to define follow-up intervals on a patient-specific basis according to individual risk assessment. The risk assessment should consider indicators such as poor oral hygiene, for example as a result of limited manual skills, cigarette consumption, previous periodontal diseases, genetic predispositions or systemic diseases such as diabetes mellitus [21].

Design of the superstructure

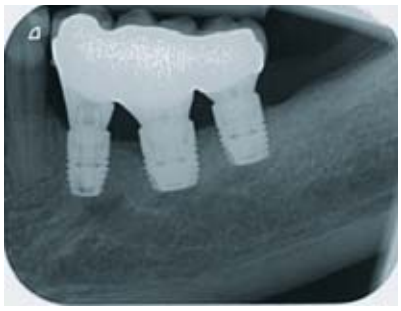
The endosteal part of an osseointegrated implant is ideally surrounded by bone and therefore not exposed to biofilm formation. This is in contrast to the transmucosal part, which is colonized by microorganisms [17]. In addition to factors such as the composition of the oral microbiome, prosthetic aspects also influence the local biofilm formation. These aspects can be the surface texture, the design of the prosthesis itself and its accessibility for oral hygiene [35, 51].

The typical central implant position in single tooth gaps in the molar region often causes restorations with much larger dimensions than the diameters of the implant shoulders. Due to the size difference, niches can develop at the transition between the implant shoulder and the restoration. This leads to difficult accessibility for oral hygiene products, which may favor the development of peri-implant diseases [35, 41].

Accessibility for cleaning can be improved by reducing the vestibulo-oral extent of the dental crown. However, esthetic limitations due to the deviating tooth morphology have to be accepted. In an in vitro study on the removability of simulated biofilms on implant-supported molar crowns, an alternative modified crown design was presented [47]. Here, the implant is placed further mesial or distal of the replaced tooth, taking into account the minimum distance between the implant shoulder and the adjacent tooth or adjacent implant. This allows a restoration consisting of a premolar crown in combination with a cantilever pontic [50]. The decisive factor is the placement of a cleaning channel in the area of the connector that is easily accessible for the patient. With this approach areas inaccessible to cleaning can be avoided with this approach, and the cleaning channel can facilitate accessibility for oral hygiene products.

Cleaning channels on implant-supported restorations guide oral hygiene products such as interdental space brushes to the peri-implant soft tissue closure and thus enable targeted cleaning. If the design of cleaning channels on the restauration itself is not possible, for example in the case of removable dentures with functional margins, customized cleaning guides can be fabricated.

For fixed prostheses, an orally and vestibularly open design is indicated, as is a convex bridge pontic design. The emergence profile should be concave and an emergence angle of ≥30 degrees should be avoided [51]. This avoids inaccessible niches and improves the rinsing function of saliva. In addition, avoiding extensive splinting can optimize access for oral hygiene aids. In edentulous jaws,



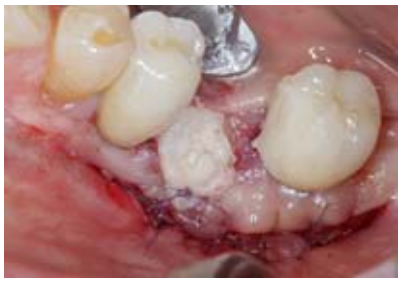


Figure 2 In this case study, a free-end situation in the third quadrant was restored with three implants (region 35, 36, 37) and a three-unit implant-supported bridge construction. Due to the crown-to-implant length ratio, the implant crowns were splinted. The central implant in region 36 had to be removed due to peri-implant complications.
a) The radiological situation shows an unfavorable dental hygienic design of the implant bridge region 36, with inaccessible niches mesially and distally and an emergence angle >30 degrees. Mesial 36 shows a bowl-shaped bony defect.
b) Implant 36 after explantation.
c) Clinical situation after explantation 36. The bridge construction was separated distally 35 and mesially 37. The bone defect was covered plastically with bone graft substitute and a free connective tissue graft, and a vestibuloplasty to enhance the attached gingiva. The implant crowns Regio 35 and 36 remained in situ and the separation points were polished.

implant-supported, removable constructions facilitate care.

Bacterial adhesion to surfaces is strongly influenced by surface roughness [10]. Thus, bacterial colonization is higher on rough surfaces than on smooth surfaces. Therefore, scratched or damaged transmucosal abutments should be replaced if possible, and surface roughness should be repolished and smoothed. However, a average roughness value (Ra) of surface roughness <0.2 µm, such as achievable by mirror polishing, does not seem to have any further effect on quantitative and qualitative bacterial colonization and can therefore be considered as a threshold value [9]. In addition to surface roughness, material-specific differences are also apparent, but their clinical influence on plaque colonization has not been clarified. For example, several studies show that titanium abutments have a stronger bacterial colonization compared to zirconia abutments. [15, 20, 40]. In addition, the composition of the salivary membrane appears to vary on different surfaces. An in vitro study showed a different protein composition of the salivary membrane on titanium surfaces compared to enamel surfaces [16]. However, an influence on the bacterial composition of the biofilm could not be detected in the different salivary membranes [31].

Occlusal overloading

Premature, excessive occlusal and/or off-axis loading can have a detrimental effect on the osseointegration of implants and, in the worst case, lead to loss [38]. The role of occlusal overloading in osseointegrated dental implants is controversially discussed. The literature describes cases in which increased biological and technical failures have occurred due to implant overloading, while other studies have not found any significant influence [23, 24, 29, 32]. The problem is that there are no values to assess overloading.

For the immediate temporary restoration of small fixed restorations static and dynamic contacts should be removed. In contrast, they cannot be dispensed with for extensive constructions. Sufficient primary stability of all implants and their splinting are then strongly recommended.

Loosened screws or crestal bone loss are the first clinically recognizable signs of implant overload. This can have many causes, such as an unfavorable relationship between implant diameter or length and the absorbed forces. The number and position of implants, the length of extensions or excessive parafunctional forces also have an influence [44].

In order to decide whether superstructures can be splinted or not, older studies recommended splinting if the ratio of crown length to osseointegrated implant length was ≥0.8 [27]. However, more recent studies do not show an increased incidence of biological or technical complications with non-blocked single-tooth implants with a mean crown-to-implant ratio between 0.86 and 2.14 [34]. Implants with splinted or non-splinted superstructures showed no difference in the extent of crestal bone loss or peri-implant parameters [3, 4]. Again, splinting may have a negative effect on cleanability [2]. In a recent cross-sectional study, implants with superstructures blocked on both sides, especially in combination with an emergence angle of ≥30 degrees and a convex emergence profile, showed an increased risk of peri-implantitis [51]. There is no evidence that a splinted or non-splinted design affects implant survival. Complications can occur with either design, although splinted restorations generally have fewer technical prob-

lems [37]. Knowing which patients are more likely to experience certain complications is of strategic importance [37].

Screwing versus cementing

In the following, the advantages and disadvantages of the respective types of fixation will be discussed and trends in peri-implant complications will be listed. Cemented reconstructions are suitable for compensating different implant axes or fabrication-related fitting inaccuracies, as well as for esthetically demanding crown designs, since there is no need for occlusal or incisal screw access. Another advantage is the passive fit of the reconstruction. In one study, cemented bridges achieved lower strain values compared to screw-retained bridges [26]. A disadvantage of cemented reconstructions is the risk of subgingival cement residues. Several clinical studies of cemented reconstructions have reported soft tissue complications due to excess cement [1, 11]. The retained cement causes increased retention of biofilm, which may cause peri-implantitis [48]. In the review by Sailer et al., cemented multiunit reconstructions showed a general trend toward more bone loss compared with screw-retained reconstructions [39]. To exclude biological complications due to excess cement residues, its proper removal is essential. In this regard, the crown margin should not be deeper than 1.5–2 mm subgingivally, as there seems to be a correlation between the amount of residual cement and the depth of the crown margin [18, 33]. The least amount of residual cement is observed when the crown margin is in an epi- or supragingival position [33]. By choosing individual abutments, the prospective location of the crown margin can be determined and deep subgingival placement can be circumvented. To avoid serious biological complications, the mentioned correlations should be taken into account when cementing the reconstruction.

Screw-retained reconstructions are suitable if there is a need for removal, for example, for dental hygiene reasons or for temporary restorations. Temporary or semipermanent cementations are also discussed in the literature. Similar to screw-retained restorations, they guarantee subsequent non-destructive removal of the restoration. However, their clinical relevance in relation to peri-implant complications is unclear.

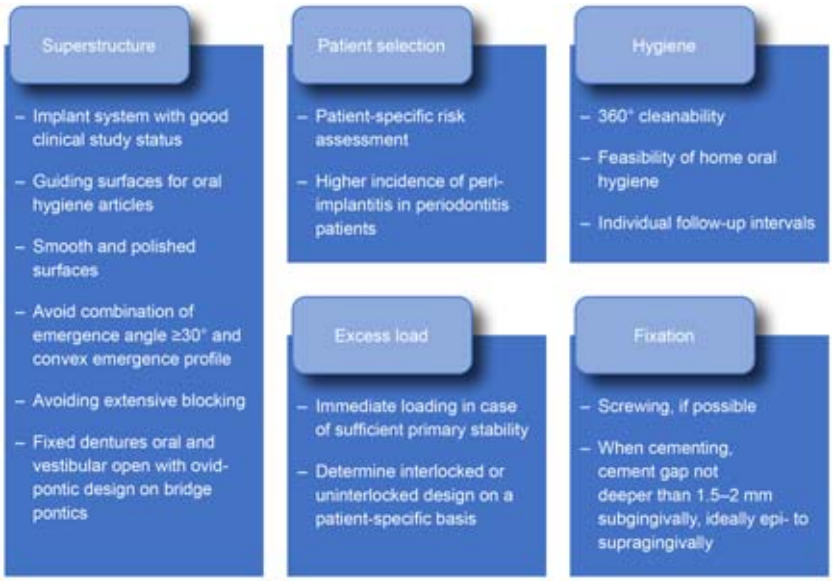


Fig. 1–3: Ufuk Adali

Figure 3 Summary of discussed aspects that should be considered in the design of prosthetic superstructures related to peri-implantitis.

The main advantages of screw-retained implant restorations include their reparability and the avoidance of cement residues [48]. In addition, if the screw-retained reconstruction fits well, severe biological failures appear to be less frequent compared to cemented alternatives [39]. However, in a systematic review, screw-retained reconstructions showed more soft tissue complications, mostly rooted in loose abutment screws; inflammation healed after their reattachment [6, 39]. The required screw access may affect esthetics and occlusion, and possibly the strength of the restoration. Thus, higher fracture rates of veneering ceramics are observed in screw-retained reconstructions, which are mostly associated with the open screw access [46, 52]. The most common technical complication in screw-retained reconstructions seems to be the loosening of the abutment screw [49]. Screw-retained reconstructions tend to have more technical problems and higher loss rates, but fewer serious biological complications [39].

Overall, soft tissue inflammation is seen with both luting options. They are associated with excess cement [1, 11] or with loose abutment screws [6]. The predominantly technical complications of screw-retained reconstructions are treatable with little effort compared with the biological complications associated with cementation. To avoid possible serious biological complications, it is recommended that implant-supported reconstructions be screw-retained when the clinical situation is appropriate. However, there is no general consensus on the superiority of one procedure over the other. The choice of fixation should be made after weighing the patient-specific advantages and disadvantages as well as the clinical situation.

In literature, a direct comparison of the estimated 5-year survival rate between screw-retained and cemented implant crowns showed no significant difference [39]. In combined fixed-removable dental restorations, there is a trend towards more complications with cemented reconstructions [39]. For fixed full-arch restorations, the risk of complications was significantly higher for cemented reconstructions than for screw-retained ones. No significant differences were seen in the survival and success rates of cemented and

screw-retained multi-unit reconstructions.

Conclusion for the practice

Peri-implantitis is a plaque-associated pathological disease and can be promoted by prosthetic factors in addition to patient-specific factors such as general diseases. In the sense of the rehabilitation concept, patient-specific risks should be known at the beginning of implant planning. With backward treatment planning, design aspects of the superstructure can be determined before implant placement. When designing the superstructure, 360° cleanability must be ensured. Extensive blocking should be avoided and guide surfaces for oral hygiene products should be created. The guide surfaces should allow targeted cleaning at the peri-implant soft tissue end. Cleaning splints can be helpful. Materials with a lower bacterial colonization can be used and rough surfaces can be reduced by polishing. The combination of an emergence angle of ≥30 degrees, a convex emergence profile and a central position within a bridge should be avoided. For immediate temporary restorations, ensure adequate primary stability. Whether a restoration is designed to be fixed or removable, splinted or non-splinted, screw-retained or cement-retained should be decided on a patient-specific basis. Due to serious biological complications caused by subgingival cement residues, screw-retained fixation should be preferred or an epi- to supragingival position of the cement joint should be aimed for. Adequate performance of oral hygiene at home and patient-specific follow-up intervals are decisive for long-term success.

Conflict of interest

The authors declare that there is no conflict of interest according to the guidelines of the International Committee of Medical Journal Editors.

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Patient-specific treatment of peri-implant inflammation

Summary: The use of dental implants in order to rehabilitate patients with fixed or removable implant-supported restorations has become widespread in recent decades. For example, according to the current German Oral Health Study (DMS V), patients were already 10 times more likely to be treated with implants in 2014 than in 1997 [41]. According to statistics from the American Dental Association, an estimated 5 million implants are placed annually in the USA alone [30]. The increasing life expectancy together with the desire for fixed restorations is expected to further strengthen this trend in the future. The steadily increasing number of implants that are placed by dentists has also been accompanied by an increase in the overall number of post-implant complications. Thus, due to the increased prevalence of biological complications, relevant patient-specific risk factors must be accounted for as part of implant planning and treatment. In this sense, a synoptic treatment concept that considers the foreseeable patient-specific risk factors for peri-implant inflammation plays an important role from the pre-implant to the post-prosthetic treatment phase. The article explores the multitude of patient-specific risk factors and the various therapeutic options available as the key to long-term implant treatment success.

Keywords: implants; peri-implant mucositis; peri-implantitis; risk factor; treatment

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Definition and diagnosis of peri-implant inflammation

When referring to peri-implant inflammation, reversible peri-implant mucositis, which is inflammation confined to the peri-implant soft tissue, must be distinguished from irreversible peri-implantitis, which also involves the progressive inflammation of the surrounding bone [4].

Due to the difficulty in diagnosing peri-implant conditions, the World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions defined the characteristics of periodontal and peri-implant health for the first time in 2017. These include the absence of mucosal redness, bleeding on probing (BOP) as well as swelling and suppuration around implants. The definition of a critical probing depth, which is no longer associated with peri-implant health, is not readily available for implants, unlike for periodontitis. In the absence of clinical signs of inflammation, the peri-implant tissues around implants may be healthy even when increased pocket probing depths above 3 mm are present. If bleeding and/or suppuration occurs during gentle probing of the peri-implant soft tissues, this is defined as peri-implant mucositis. If there is a combination of bleeding/suppuration with an increasing probing depth compared to previous examinations, or probing depths of ≥6 mm and radiological detectable bone resorption beyond the initial bone level after implant placement, then this is referred to as peri-implantitis [11]. In the absence of initial radiological findings, bone resorption ≥3 mm apical to the intrabony part of the implant is considered indicative of peri-implantitis [91].

The prevalence of peri-implantitis has been estimated to vary between 10 and 29 % [24, 42]. The variation of these prevalence figures is primarily due to the complex definition and diagnosis of peri-implantitis as well as a high heterogeneity of study criteria [67].

The prevalence of mucositis is on average 40 % and of peri-implantitis 21.7 % (95 % CI 14–30 %) according to systematic reviews [24]. Half of the implants affected by peri-implantitis become diseased within 3 years, and overall, peri-implantitis is diagnosed considerably more often 5 years consecutive to prosthetic restoration [86, 87]. It is assumed that initial mucositis can develop into peri-implantitis and that peri-implant bone resorption accelerates over time [102].

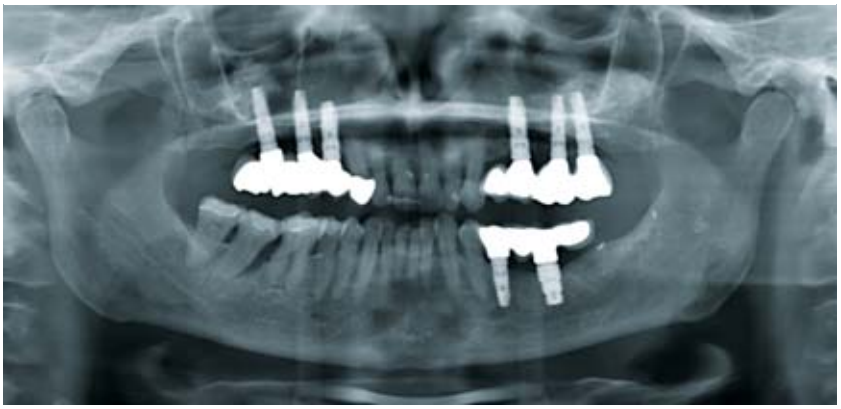

Figure 1 Orthopantomogram (initial condition).

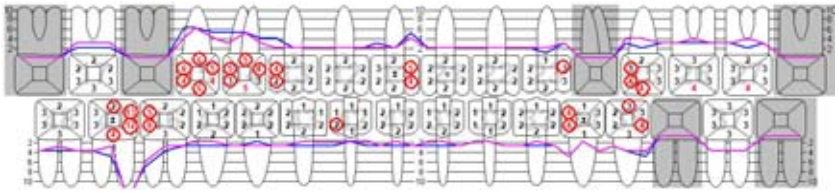

Figure 2 Clinical probing values of the entire dentition (initial condition).

For the classification of peri-implantitis and corresponding peri-implant bone lesions, a classification of different defect morphologies – especially against the background of the various therapeutic options – is recommended. In this respect, intrabony defects (Class I) are distinguished from horizontal supracrestal defects (Class II). The supracrestal portion is defined as the distance between the transition from the smooth to the machined implant portion and the peri-implant crestal alveolar bone [108].

Intrabony defects can be divided into purely vestibular or oral dehiscence defects (Class Ia), vestibular or oral dehiscence defects with additional semicircular portions (Class Ib), vestibular or oral dehiscence defects with additional circular bone resorption (class Ic), and into circular bone resorption with vestibular and oral dehiscence defects (class Id) or bilaterally preserved compact bone (class Ie).

Horizontal and intrabony defects mainly occur together. According to current data, 55.3 % of peri-implant bone defects belong to Class Ie [103].

Patient-specific risk assessment of treatment-relevant risk factors

Possible risk factors include patient age, gender, gene polymorphisms, cardiovascular disease, rheumatoid disease, osteoporosis, condition of residual dentition, implant design and surface as well as implant site and type of restoration. In the following chapter, the 5 most important treatment-relevant risk factors relating to peri-implant inflammation are discussed in detail [102].

Association of periodontitis and peri-implant diseases

The similarity in the etiopathogenesis of peri-implant and periodontal inflammatory diseases highlights that periodontitis is a risk factor for biological complications and failures of dental implant treatment [42]. The corresponding causal association between plaque formation around implants and peri-implant mucositis has been demonstrated. However, the reaction of hard and soft tissues to

the pathological biofilm around teeth and implants is only to some degree comparable. The microflora found around teeth and implants, that have been exposed to the oral environment for 6 months, is already comparable; however, it does not lead to the development and progression of peri-implant disease in every case. Periodontitis is considered a risk factor for peri-implantitis due to the possible transfer of periodontal pathogens onto the implant surfaces and the reservoir effect of existing periodontal pockets [42]. Additionally, genetic factors are strongly involved in the etiopathogenesis of periodontitis and peri-implantitis and they lead to a correspondingly high susceptibility to both diseases in the same patient group [12, 34–36]. The occurrence of peri-implant diseases clearly correlates with the predisposition and severity of existing periodontitis in the individual patient. However, due to the anatomical conditions of peri-implant tissues, inflammation-induced bone resorption often proceeds faster than at natural teeth. Therefore, patients with severe forms of periodontitis have significantly lower implant survival rates (88–98.4 %) than patients with moderate periodontitis (92.8–100 %) or periodontally healthy individuals (96–100 %) in a 5- to 10-year period after periodontal treatment and implant placement [58]. Implant success after 10 years is significantly lower in patients with generalized, severe periodontitis (83.33 %) than in periodontally healthy patients who have success rates of up to 100 % [66, 114]. Overall, periodontally treated patients with initial stage I–II periodontitis have higher implant survival rates and less bone resorption around implants than patients with more pronounced stage III–IV periodontitis [58, 86]. For more severe grade C periodontitis, much lower survival and success rates and greater marginal bone resorption [21] are observed than for grades A and B [66, 86, 114]. In particular, patients with a history of severe periodontitis accompanied by poor plaque control and irregular maintenance therapy are at significantly higher risk for the occurrence of peri-implantitis [23, 81, 86].

Currently, the strongest risk factors for peri-implantitis include remaining large pocket depths, lack of follow-up care, poor oral hygiene and severe forms of periodontitis. Even localized, remaining inflammation (PPD ≥6 mm with BOP) leads to a 5-fold higher risk of inflammatory processes around implants compared to successfully treated periodontitis [17].

Poor oral hygiene/irregular maintenance therapy

The lack of compliance during maintenance therapy is associated with tooth loss and attachment loss [6, 8, 121]. The relationship between microbial plaque and diseases such as gingivitis and periodontitis has been demonstrated in numerous studies [7, 8, 61]. Causal therapy in the sense of plaque removal showed improvements in inflammatory lesions in plaque-associated forms of etiopathogenesis [61]. A subsequent study involving mucositis patients demonstrated that efficient plaque control was critical for the prevention of peri-implantitis [18]. Thus, the incidence of peri-implantitis over a 5-year period was significantly lower in patients undergoing maintenance therapy (18 %) than in patients not undergoing maintenance therapy (44 %). A study by Roccuzzo et al [85] also found a higher prevalence of peri-implantitis over a 10-year period in the absence of maintenance therapy (41 %) than in the presence of maintenance therapy (27 %). Patients who attended maintenance therapy less than 2 times per year showed an increased risk of developing peri-implantitis (OR 4.69; 95 % CI 1.17–18.79).

Moreover, a strong association between inadequate home-based oral hygiene and peri-implantitis was shown in 4 studies with an odds ratio ranging from 5 to 14 [3, 27, 90, 101]. However, conflicting findings have also been published [53, 65, 96], despite the fact that a singular plaque index recording in these studies generally does not reflect an exhaustive means of measuring the long-term oral hygiene status. Serino and Stroem investigated the oral hygiene ability of patients who displayed peri-implantitis at implant-supported restorations [110] and were able to show that peri-implantitis was diagnosed in only 18 % of the areas accessible to oral hygiene and in 65 % of the areas not accessible to hygiene.

Smoking

Smoking is associated with chronic periodontitis, attachment loss and tooth loss [9, 116]. There is also an association between smoking and peri-implantitis [25]. In a 10-year study by Karoussis et al, smokers displayed peri-implantitis at 18 % of all implants and non-smokers at only 6 % of all implants. In addition to the incorporation of nicotine, cotinine, and their decay products into periodontal tissues, smoking produces hydroxide and peroxyl radicals which destroy host DNA, cause lipid peroxidation of the cell membrane, damage endothelial cells, and induce vascular smooth muscle growth, thus causing numerous tissue changes [117]. Reactive oxygen species (ROS) also activate the formation of proinflammatory mediators such as interleukin-6, tumor necrosis factor-alpha or interleukin-1 beta which are important in the pathogenesis of peri-implant diseases. Smoking also leads to a reduction of blood vessel density [84] and to the exacerbation of the inflammatory lesion through genetic variation in the biotransformation of N-acetyltransferase-2, cytochrome P450, CYP2E4, and gluthathione S-transferase [51, 52]. Moreover, the functional capacity and number of polymorphonuclear neutrophil granulocytes decreases in smokers [33, 72] in relation to a cytotoxic effect of nicotine on fibroblast migration [26].

Lindquist et al. showed considerably greater crestal bone resorption in smokers than in nonsmokers [60]. However, contrasting results from Aguirre-Zorzano et al. showed a peri-implantitis prevalence of 15 % in 239 patients over 5 years, with no increased risk among smokers [3, 20, 23, 76].

On the whole, smoking cannot be considered a relevant predictor of peri-implantitis development, but it should be considered a cofactor, especially when other risk factors such as periodontitis are present. Patients

with existing cofactor smoking and a periodontally compromised dentition have a 4.6-fold increased risk of peri-implantitis compared to periodontally compromised nonsmokers [113].

Future studies should survey the cumulative amount of nicotine abuse in "pack-years" and differentiate between smokers, former smokers, and nonsmokers in order to further elucidate the associations [25].

Diabetes mellitus

With a worldwide prevalence of approximately 8 % in adults [111], diabetes mellitus is considered another important risk factor for peri-implant disease [11] and periodontitis [29]. Due to the parallelisms in the pathogenesis of peri-implantitis and periodontitis, it is suspected that biological complications at implants are favored by this metabolic disease. Since there are bidirectional relationships between periodontitis, peri-implantitis and diabetes mellitus, glycemic control (HbA_{1c} value) and its re-evaluation are mandatory as part of patient-specific treatment. Hyperglycemia results in the formation of advanced glycation end products (AGE) which dock to inflammatory cells via their receptor (RAGE) and lead to an increased release of inflammatory molecules (reactive oxygen species and cytokines), a reduction in chemotaxis and the adhesion performance of inflammatory cells as well as an increase in bacterially induced inflammation of peri-implant tissues [31]. Collagen cross-linking via AGE also leads to more difficult turnover of the peri-implant connective tissue [31]. A large number of studies have found a higher risk of peri-implantitis in patients with poorly controlled diabetes mellitus. Ferreira et al. showed a peri-implantitis prevalence of 24 % in untreated diabetic patients or patients with a blood glucose level of ≥126 mg/dL compared with 7 % in the control group of non-diabetic patients, which corresponds to an odds ratio of 1.9 [27]. Patients who received their diabetes diagnosis at the time of implant placement showed a 3-fold higher risk of developing peri-implantitis at the time of the 11-year follow-up evaluation [19].

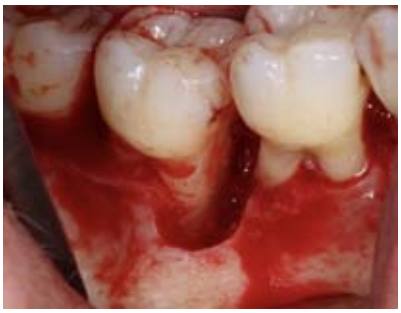

Figure 3 Illustration of the morphology of the mesial intrabony defect at 46 by means of simplified papilla preservation flap after re-evaluation of the previously performed conservative periodontal therapy.

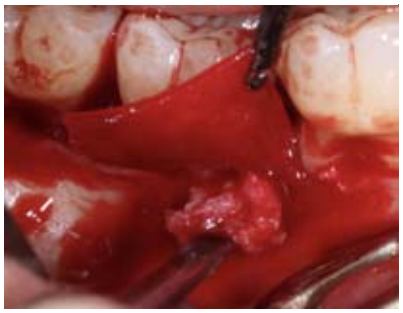

Figure 4 Debridement of the root surface with subsequent membrane positioning in the context of guided tissue regeneration and defect filling with autologous bone.

Tawil et al. studied 45 patients with diabetes mellitus over an average duration of 42 months (1–12 years); they diagnosed no peri-implantitis in patients with an HbA_{1c} ≤7 %, but in the group of patients with HbA_{1c} values between 7 and 9 %, they diagnosed peri-implantitis at 6 of 141 implants [115].

Diabetes is thus considered an important potential risk factor for peri-implantitis [76, 102]. More specifically, it has been shown that diabetics have a two-fold higher risk of peri-implantitis than non-diabetics (OR 2.5, 95 % CI 1.4–4.5) [25]. From 3 studies in which the information on diabetes mellitus was collected, not only anamnestically, but also clinically, 2 studies showed a significant effect of diabetes [27] or HbA_{1c} levels [115] on peri-implantitis.

Attached and/or keratinized mucosa

Although previous reviews [119] have shown that the lack of attached mucosa has no negative influence on peri-implant health, further meta-analyses, mainly based on cross-sectional studies, have conveyed that lower plaque accumulation, less tissue inflammation, recession, and clinical attachment loss occurs when a minimum width of 1–2 mm keratinized mucosa is present in comparison to when this minimum width is absent [59]. A lack of attached mucosa may negatively affect the ability of the patient to clean [59]. Pain-free, home-based cleaning of implant superstructures is considered an important goal in patient-specific treatment. The attached mucosa – independent of muscle movements – should not allow any microorganisms to deposit on the peri-implant transmucosal attachment due to crevice formation in the area of the implant neck [55]. Recent reviews have shown significantly less peri-implant inflammation and lower plaque and gingival indices in patients with at least 2 mm of keratinized or attached peri-implant mucosa [13, 44, 59]. Although less gingival recession and attachment loss occurred with sufficient mucosa, no significant differences could be seen with respect to probing depth values [2, 44, 96, 123]. A non-significant trend indicates increased bone resorption when there is insufficient mucosa [46, 96]. Rokn et al. demonstrated a lack of keratinized mucosa as a statistically significant risk factor for peri-implantitis (OR 3.89; 95 % CI 2.34–5.98) [90]. Moreover, Souza et al. found increased discomfort during home-based oral hygiene in areas where there is less than 2 mm of keratinized mucosa, which was accompanied by correspondingly higher plaque values and increased bleeding on probing [112].

Treatment options for peri-implant inflammation

Prevention of patient-specific risk factors

Patient-specific treatment of peri-implant inflammation comprises of a synoptic treatment concept with, on

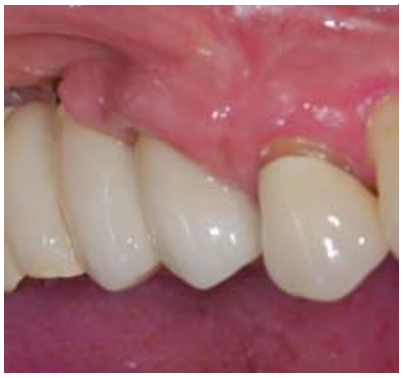

Figure 5 Peri-implantitis in region 15 and 16 (initial clinical condition).

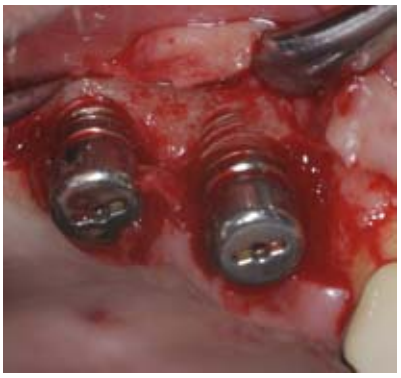

Figure 6 Surgical treatment of peri-implantitis in region 15 and 16 (horizontal bone resorption) and removal of the superstructure 8 weeks after closed scaling and decontamination of the implant surface.

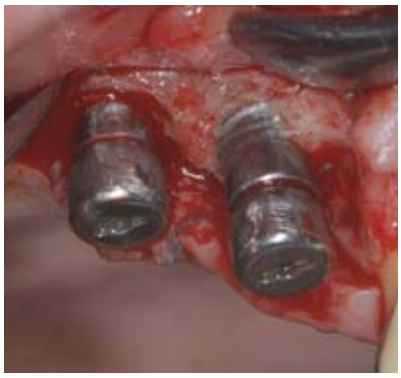

Figure 7 Implantoplasty using rotary instruments and subsequent removal of the granulation tissue and direct insertion of the restoration.

the one hand, attention to the detailed risk factors so as to prevent the development or renewed progression of peri-implant infections and, on the other hand, anti-inflammatory, if possible reconstructive treatment of peri-implant lesions.

Fundamental to the success of implant treatment is the long-term avoidance of biological, technical and esthetic complications. At the biological level, the absence of peri-implant mucositis, peri-implantitis and the establishment of stable soft tissue conditions is necessary, especially as part of maintenance therapy after the active treatment of peri-implant infections. Biological complications at implants differ in their frequency and severity in patients with and without periodontitis. The implementation of careful anti-infective periodontal therapy with the reduction of inflammatory signs and probing depth values prior to the treatment of peri-implant inflammation is thus mandatory (Fig. 3–4).

For the successful long-term treatment of peri-implant inflammation, particularly from the patient-specific point of view, it is essential to design the prosthetic restoration as close as possible to the natural appearance of the teeth, with correspondingly good hygiene characteristics and an optically and functionally satisfactory result; often, this can only be achieved by restoring the lost tissue dimensions.

Tooth loss leads to both bone and soft tissue loss, which are often exacerbated by atrophic bone remodeling processes. It is not uncommon to have partially limited bone volume at the time of the indication for implant placement. Augmentation of the alveolar ridge may be required in order to insert an implant in a physiological position, with sufficient bone quantity, and a prosthetically correct position.

The extent to which the crown-to-implant length ratio has an influence on the survival, marginal bone level or prosthetic complications in the absence of augmentation is controversially discussed. Some reviews concluded that no negative influences exist [69, 75]. In contrast, other systematic reviews observed a higher incidence of prosthetic complications such as abutment loosening or fractures, mainly in posterior jaw regions. Restoration of the near-original dimensions of the hard and soft tissues can minimize these risks in the long term [64]. Moreover, the esthetic result is significantly improved and the ability to maintain oral hygiene, thus ensuring the prevention of inflammatory processes [44].

Treatment of peri-implant mucositis

If peri-implant mucositis develops despite consideration of these recommendations and risk factors, the causal therapy of the existing risk factors needs to start with the utmost priority; this includes smoking cessation, control of diabetes mellitus and specific oral hygiene instruction. Localized plaque-induced inflammation should be eliminated by non-surgical mechanical plaque removal, optimization of oral hygiene skills, and inclusion in a regular maintenance therapy program [73]. Efficient plaque removal without damaging the implant structure is the primary goal [63]. Home-based oral hygiene can be carried out using manual or electric toothbrushes and appropriate interdental brushes [83].

In the case of isolated inflammatory sites in combination with cemented restorations, remaining cement remnants should be taken into account and gently removed by non-surgical cleaning. In cases where non-surgical cleaning is unsuccessful, the removal of the prosthetic restoration and surgical cleaning and cementation under direct view are recommended [83] because the removal of cement remnants leads to a significant improvement of peri-implant tissue health [120].

The question of whether fixed prosthetic restorations should be screw-retained or cemented is still controversially discussed in literature. In a 2016 review, no clinically relevant differences were found with regard to marginal bone loss at the implant site for screw-retained or cemented restorations [57]. Other authors found increased plaque adhesion to cement remnants in combination with increased incidence of peri-implant in-

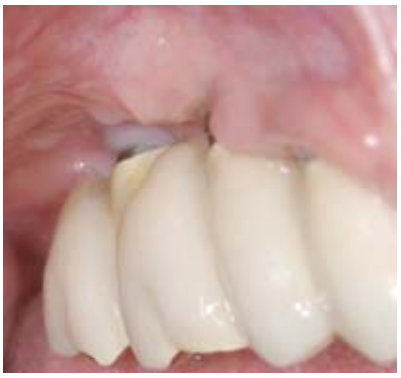

Figure 8 Condition after surgical peri-implantitis treatment with insufficient soft tissue (3 months).

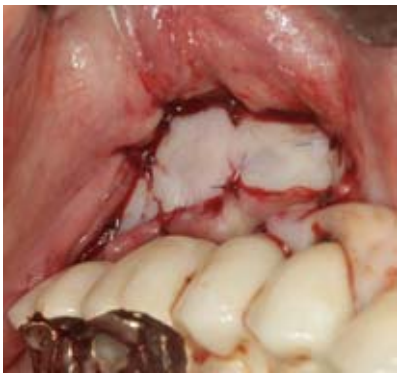

Figure 9 Harvesting of free mucosal graft (right palate) and vestibuloplasty in order to widen the keratinized mucosa.

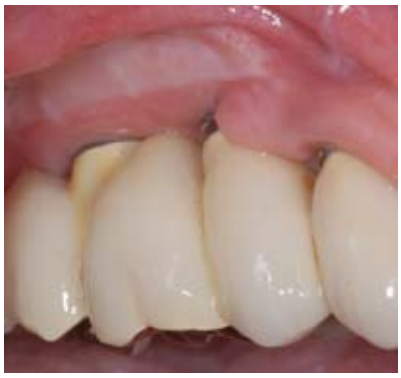

Figure 10 Stable peri-implant and inflammation-free soft tissue condition at the time of a 3-year follow-up check of region 15 and 16.

flammation when methacrylate-based cements were used [71]. In periodontitis patients, the use of screw-retained restorations appears to be desirable because it reliably excludes retention of cement remnants and makes the construction easier to remove in cases of biological or technical complications. On the other hand, technical complications such as fracturing of the veneering are more common among screw-retained restorations [99]. Thus, when choosing cemented restorations, the fabrication of customized, anatomical abutments is helpful for preventing a deep subgingival position of the cement gap and for ensuring the removal of cement remnants. In addition, the avoidance of overhanging margins or concave surfaces on crowns and bridges should be aimed for in order to facilitate ideal home-based oral hygiene.

During mechanical cleaning, titanium and carbon fiber instruments as well as plastic and teflon coated ultrasonic systems are used specifically in order to protect the implant surface [97]; this appears to be advantageous for any potential augmentative therapy approaches in the future. However, it must be noted that debridement is in this case more ineffective and remnants may be left over on the surface [122]. In a randomized controlled trial, it was shown that the use of glycine powder systems gave better results for bleeding on probing in comparison to mechanical cleaning with carbon fiber instruments [40, 98]. Nonsurgical therapy is considered a successful treatment step in reversible peri-implant mucositis and is subsequently characterized by the absence of bleeding or suppuration on probing [73].

Treatment of peri-implantitis

Peri-implantitis lesions can be differentiated into early and late infections. Early peri-implant inflammation occurs immediately or in the first weeks after implant placement and it is mostly caused by postoperative wound healing disorders. Late peri-implantitis is usually diagnosed after the implant's osteointegration has been completed and its prosthetic restoration [82].

The removal of the affected implant is usually indicated upon clinical and radiological diagnosis, as well as, very low Resonance Frequency Analysis (RFA) values or very high Damping Capacity Analysis (DCA) values, deep tapping sounds, mobility and large probing values, which check for osseointegration [73]. In all other cases, the peri-implant inflammation must be permanently reverted to a stagnation phase, beginning with a non-surgical treatment phase and the adjustment of all oral hygiene parameters.

The basis for systematic and continuous prevention and treatment of peri-implant diseases is the original CIST concept (cumulative interceptive supportive therapy or antiseptic cumulative supportive therapy) according to Mombelli and Lang [68]. The CIST concept is a step-by-step model divided into 4 treatment steps. Depending on the diagnostic course, the modular therapy guide initially includes hygiene instructions and professional dental cleanings (part A), followed by chlorhexidine rinses, gel applications (part B) and systemic antibiotic medication (part C) as well as subsequent surgical interventions with either resective or regenerative treatment approaches (part D). However, especially in the further development of patient-specific treatments, the existing risk factors must be recognized and adjusted, and the evaluation of the treatment at each step must not be made according to rigid consideration of the probing values, but according to the change in probing values over time [43].

Nonsurgical treatment of peri-implantitis can be expected to reduce bleeding on probing, but it can only result in a limited improvement in probing values [77, 118]. When adjuvant irrigation solutions or antibiotics were used, such as minocycline products and tetracycline derivatives, they proved to be effective and improved the bleeding on probing values as well as the probing depths [10, 14, 78, 79, 100]. However, the administration of systemic antibiotics should be avoided for nonsurgical procedures [77]. The adjuvant use of Nd:YAG and Er:YAG lasers in addition to mechanical therapy has also been shown to have only short-term

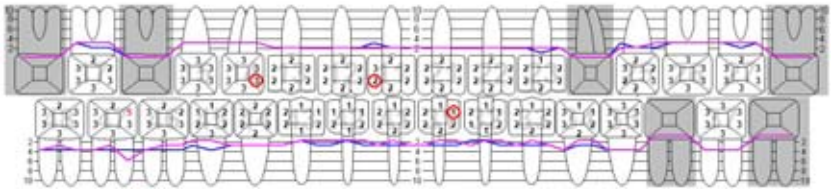

Figure 11 Clinical probing values of the entire dentition 3 years postoperatively (final findings).

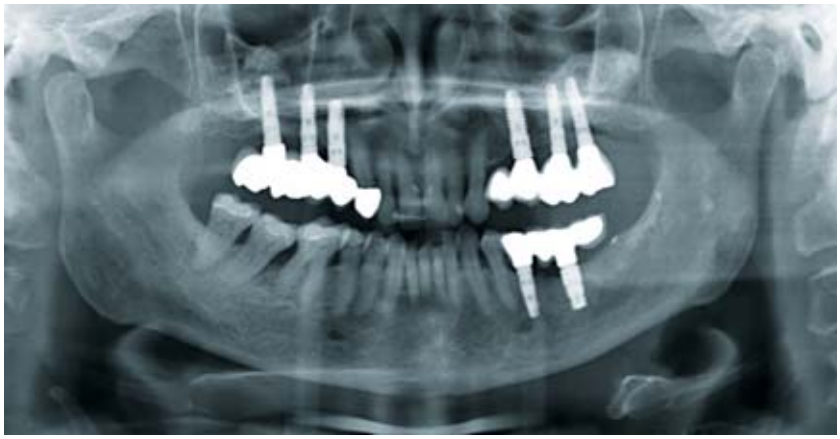

Figure 12 Orthopantomogram 3 years postoperatively (final findings).

success, which lasted a few months in terms of bleeding on probing and probing depths [1, 80].

Six weeks after the nonsurgical procedure, surgical, mechanical debridement including chemical decontamination of the implant surface should be performed. Access flaps, resective therapy approaches with or without implantoplasty, or augmentative procedures can be used during this operative intervention. In this context, the bony defect morphology and the position of the affected implant – inside or outside the esthetic area – are considered to be the decisive factors in further treatment planning. In principle, augmentative measures for intrabony components such as bowl-shaped defects (class Ie [108]) and 3- or 4-walled bone defects can achieve improved clinical and radiological therapeutic results in addition to anti-inflammatory ones. The remaining bony defect morphologies are usually treated with resective therapeutic procedures.

Surgical access flaps and resective treatment approaches are indicated for supracrestal bone defects (horizontal bone resorption) with exposed implant threads [45, 50]. Resective treatment of peri-implant inflammation can recontour the bone and reduce probing values. This can be performed together with or without smoothening of the implant surface. In the esthetic region, an access flap with a strictly intrasulcular incision can be used while preserving the soft tissue; in the posterior region, an apically displaced flap can be used [45]. In esthetic regions with moderate bone loss and shallow bone defects, the combination of surgical debridement with a free connective tissue graft is a recommended option in order to achieve significant clinical improvement while still avoiding the high risk of recession [37, 105]. In posterior areas, resective treatment together with implantoplasty lead to improved clinical and radiological results after a 3-year follow-up compared to the control group with only the resective approach without implantoplasty (STM: 1.64 ± 1.29 vs. 2.3 ± 1.45 mm) [93, 94] (Figs. 5–6). For implantoplasty, flame or ellipse shaped carbide burs (30 mm length) can be used with normal (12 cutting edges) and ultrafine (30 cutting edges) finishing grades. The smoothening of the surface is finalized with Arkansas and Greenie tips. However, the remaining titanium particles in the tissue should be reduced by means of gauze exposure and excision of the granulation tissue after implantoplasty or, depending on the indication and diagnosis, implantoplasty should be limited to the supramucosal areas before flap formation, since the effect of tissue reactions to the remaining titanium with regard to progressive peri-implant inflammation is currently unclear [45, 102]. In order to improve the course of treatment, it is recommended to remove the superstructure before the respective operative intervention, especially in the case of implantoplasty; in this way, the superstructure can be adapted with regard to its oral hygiene design before being reinserted [45]. Adjuvant systemic antibiotics in the case of resective procedures did not result in significant clinical and radiological long-term improvement [16].

Augmentative procedures are indicated for bowl-shaped bone defects (Class Ie [108]) and 3- or 4-walled bone defects where the bone contour is preferably preserved as a scaffold shape, especially in the case of moderately rough implant surfaces after considering the corresponding existing risk factors [29, 73, 88, 103, 108]. Pre-operatively, especially the implant position and design as well as the hygienic suitability of the prosthetic reconstruction should be critically evaluated [73]. For the execution of augmentative surgical interventions, the use of bone or bone substitutes in combination with or without a membrane technique for guided tissue regeneration, or in combination with biologically active agents, primarily enamel matrix protein derivatives, bone morphogenetic proteins (BMPs) or platelet-rich fibrin membranes (PRF), is available [74]. In the majority of studies, the augmentative interventions resulted in an improvement of the clinical and radiological parameters over a study period ranging from 6 months to 7–10 years [74]. Bleeding on probing reduced by an average of 25.9 % [32] to 91 % [28] over the follow-up period of up to 7 years. The probing values also decreased between 0.74 mm and

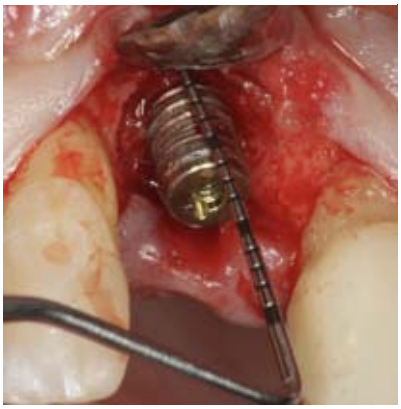

Figure 13 Combination of a supracrestal and Class Ie defect in the esthetic maxillary anterior region. After non-surgical treatment, surgical cleaning and decontamination of the implant surface is carried out.

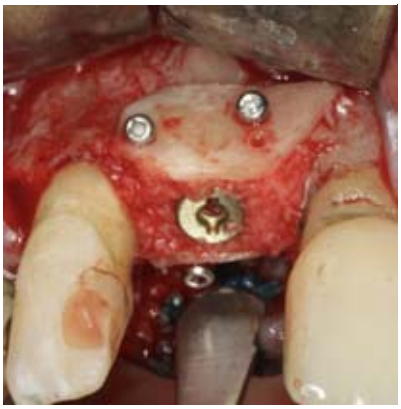

Figure 14 Augmentation of the defect using the biological 3D shell technique according to Khoury and retromolar bone harvesting with subsequent closed wound healing.

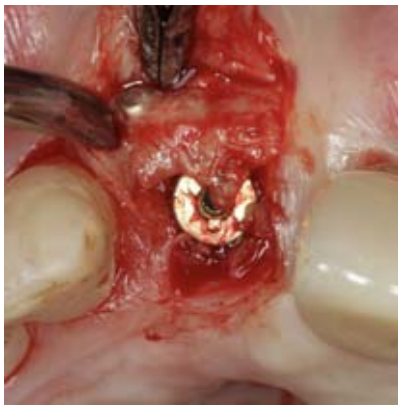

Figure 15 Re-entry at the exposed site after 3 months with complete reconstruction of the bony alveolar process and insertion of the existing prosthetic restoration.

Fig. 1–15: P. Keeve

5.4 mm [48, 104]. The type of surface decontamination had no significant effect on these parameters [22, 48, 54], and thus, cleaning with saline-soaked gauze can be considered as the standard for all surgical procedures [107]. Titanium granules as a filler did not show a positive influence on clinical parameters in augmentative procedures compared to simple access flaps [5, 39]. In 2 studies, there were no significant differences between the use of autologous bone alone and the combination with resorbable [95] and non-resorbable membranes [48]. In contrast, one study provided better clinical results when bone graft substitute was combined with a membrane [106]. Furthermore, the addition of enamel matrix protein derivatives did not improve probing depths and bleeding on probing compared to the control group with access flaps [38]. Therefore, long-term studies currently show no evidence for the clinical superiority of any particular combination in [74].

The question of whether to allow open or closed healing [92] and the benefit of adjuvant systemic antibiotics [74] also cannot be clearly answered on the basis of the current state of literature. If the superstructure permits a non-destructive removal and, in particular, the use of membrane technology where a correspondingly increased risk of exposure is considered [48], closed healing may be favored.

Stabilization and improvement of the treatment outcome

The described augmentative techniques, in contrast to the purely surgical access flaps and resective treatment approaches, aim not only to achieve an anti-inflammatory effect, but also to improve the therapeutic outcome in terms of probing depths, attachment level and defect filling. Additional options for hard and soft tissue management are described below.

Hard Tissue Management

Generally, augmentative procedures are limited to the intrabony region, so supracrestal implant surfaces should be treated with either debridement only or supracrestal limited implantoplasty, depending on the risk profile [104]. In the esthetic area, 3D restoration of the alveolar process including the supracrestal portions may be considered in the absence of risk factors – currently without scientific evidence. The author recommends the shell technique as a modification to the autogenous block augmentation for vertical bone resorption consecutive to peri-implantitis, so as to improve healing and bone stability [49] (Figs. 13–15). This concept of bone block grafting from the retromolar mandible uses a thin block graft as a biological membrane, which gives the particulate bone graft material the desired shape and dimension. Particulate bone has an increased surface area with a high regeneration potential and thus mostly improves osteoconduction. For closed healing, absolutely tension-free wound closure with periosteal slitting or adjunctive rotation/swing flaps is mandatory.

Soft Tissue Management

Before, during and after surgical peri-implantitis treatment, all risk factors (e.g. lack of attached keratinized mucosa) must be immediately checked [109]. If there is a strong muscular influence on the peri-implant soft tissue, the width of the keratinized mucosa should be increased previous to surgical augmentation therapy in order to optimize soft tissue handling, including primary wound closure. In the remaining cases, to prevent recurrence, this potential risk factor can be surgically resolved after successful treatment of the peri-implant inflammation [109]. In most cases, there is a deficit of attached keratinized mucosa after hard tissue augmentative or resective surgery. In this regard, despite limited scientific evidence, the absence or inadequate width of keratinized peri-implant mucosa is considered a source of risk for recurrent peri-implant disease. The presence of an adequate keratinized collar reduces plaque accumulation, tissue inflammation, mucosal recession, and attachment loss [44]. From a clinical perspec-

tive, a minimum width of 2 mm of keratinized, attached peri-implant mucosa is recommended in order to improve peri-implant soft tissue stability, allow the patient to adequately clean and minimize subsequent risks due to increased plaque accumulation. In the absence of this keratinized mucosa, it is imperative to utilize a free mucosal graft so as to improve the clinical situation. [15, 89, 109] (Figs. 8–10). In this regard, autologous free mucosal grafts from the palate show better results in terms of widening the keratinized mucosa compared to vestibuloplasty alone, acellular dermal matrices, or xenogeneic collagen matrices [15, 62].

Follow-up care

Follow-up care (supportive periodontal therapy) is key to the successful, long-term treatment of peri-implant inflammation [73] and it only functions when potential patient-specific risk factors are taken into consideration. During maintenance therapy, intensive, repetitive instruction, demonstration, and motivation of the patient is indispensable [47]. Moreover, the peri-implant probing depth values must gently be recorded and the re-evaluation of effective home-based as well as professional hygiene skills must be carried out. The recall interval should be selected according to the individual's risk profile [56, 70], whereby patients with previous peri-implant inflammation are generally considered to be at an increased risk [73]. For this reason, a close-meshed 3-month interval for supportive periodontal therapy should always be selected initially, which can always be adapted on a patient-specific basis according to existing risk factors.

Conclusion

Patient-specific treatment of peri-implant inflammation is based on a synoptic treatment concept with special attention to therapy-relevant risk factors. The prevention of newly recurring peri-implant infections and anti-inflammatory, if possible reconstructive, treatment of peri-implant lesions is considered to be the therapeutic goal.

With successful active periodontitis treatment, the establishment of adequate oral hygiene including prosthetic and/or soft tissue conditioning, as well as, possible nicotine reduction and the adjustment of diabetes mellitus with HbA_{1c} target value <7, significant risk factors can be eliminated and the initial conditions for the subsequent treatment of peri-implant inflammation can be created.

Peri-implant inflammation should be initially treated with non-surgical mechanical plaque removal and antimicrobial rinses. After re-evaluation, surgical mechanical debridement using access flaps, resective therapy approaches together with or without implantoplasty, or augmentative procedures may be used. In principle, resective therapy procedures together with or without implantoplasty can be used for supracrestal bone defects (horizontal bone resorption) and augmentative measures for intrabony components such as bowl-shaped defects. In the context of patient-specific treatment of peri-implant inflammation, particular importance is accorded to follow-up care and the accurate re-evaluation of risk factors.

Conflict of interest

P. L. Keeve is a lecturer among others for the companies Dentsply Sirona, Straumann, Hager & Meisinger, Stoma Dentalsysteme and Resorba. There is no direct cooperation with these companies for this article. No studies on humans or animals were conducted by the author for this article. The ethical guidelines stated in each case apply to the studies listed.

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Implant planning and surgical aspects to reduce the risk of peri-implantitis

Abstract: Peri-implant inflammation is still a frequent complication in dental implantology despite highly developed surgical techniques and implant components. The development of peri-implant inflammation may not only have post-implantological causes, but pre-implantological factors also play a role. In addition to the design of the prosthetic restoration, correct planning of the implant position and surgical preparation of the implant site are particularly important for the long-term success of dental implants. This paper deals with these pre-implantological factors with special emphasis on implant planning, hard and soft tissue management and navigated implant placement, taking into account current relevant literature.

Keywords: hard and soft tissue management; navigated implantation; peri-implantitis; pre-implant procedure

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Introduction

In Germany alone, more than 1,300,000 dental implants are placed annually [3]. The complication rate is still about 20 % over an observation period of 5 years, and peri-implant inflammation is one of the main causes of implant failure [2, 4]. Nevertheless, implantological treatment of the gap dentition or the edentulous jaw has become an indispensable part of the treatment spectrum in modern dentistry, especially because the range of indications for dental implants is constantly expanding due to further developments in manufacturing techniques and materials. Today, modern pre-implantological and implantological surgical techniques allow implant restorations in almost all areas. However, depending on various influencing factors, the long-term prognosis varies.

The focus of this article is on those aspects that influence the risk of complications occurring during the surgical procedure of implant restoration. General and general medical risk factors for implant complications, such as medications or pre-existing conditions, are not the focus of this article; rather, it is assumed that absolute and relative contraindications are recorded and taken into account on a patient-specific basis.

Figure 1 shows a flow chart for a standardized procedure that can reduce the occurrence of complications in the period leading up to implant placement. The main focus is on avoiding unfavorable hard and soft tissue conditions in the implantation region or improving unfavorable conditions prior to implant placement coupled with sensible backward planning and correct selection of the appropriate implant types.

In addition to the special requirements for the actual implantation, the planning of the desired implant position, taking into account the subsequent implant-prosthetic restoration, plays a particularly important role. Jepsen et al. demand that the selected implant position and the prosthetic restoration must be chosen or designed in such a way that they are accessible to regular oral hygiene at home as well as to professional prophylaxis [12]. According to Schwarz et al., however, there are still few data on this in the literature, so that the underlying evidence regarding the pre-implantological factors influencing the development of peri-implant inflammation is still limited [23]. Implant planning that not only takes into account in advance surgical aspects such as bone quality and quantity, but also considers the prosthetic restoration planned later in terms of the necessary implant diameter, subsequent soft tissue management and hygiene capability, helps to reduce the risk of peri-implant soft tissue inflammation and established peri-implantitis. For example, according to Romanos et al., larger diameter implants show greater degradation of the buccal bone lamella over time than thinner implants with a diameter ≤3.75 mm [21]. This shows that with regard to the selection of the correct implant position, the hard and soft tissue located in the desired area must be taken into account in addition to the planned restoration and its expected loading. Increased mucosal mobility, i.e., the absence of keratinized attached gingiva in the region of implants, may trigger peri-implant inflammation [23]. Pre-implant assessment of the surrounding soft tissue at the planned implant site is therefore particularly important. Often there is increased mucosal mobility in the region of the frenulum and labial frenulum, especially if atrophy of the alveolar ridge has occurred after tooth loss. Increased alveolar ridge atrophy also leads to a change in the positional relationship between the alveolar ridge and the enveloping folds, in the vicinity of which the proportion of keratinized attached gingiva is also reduced.

Today, drilling templates can be used to transfer the planned implant position(s) very precisely to the clinical situation in the patient's mouth [19]. Although the digitally supported modern planning and treatment options already offer good therapy safety, dental implants unfortunately exhibit the relatively high complication rate already mentioned above.

The aim of this review article is to first provide an overview of the so-called backward planning method, followed by a closer look at pre-implantological surgical strategies and guided implant placement. Finally, a brief review of the currently relevant literature will be given. By way of introduction, the following general question should be asked: Is there an ideal implant position and how can it be found?

Pre-implantological backward planning

An ideal implant position depends on various aspects. Surgically, good primary stability and subsequently good osseointegration are of decisive importance. A good initial bony situation, complication-free implant placement and postoperative bacteria-proof mucosal closure are important for achieving these goals. In

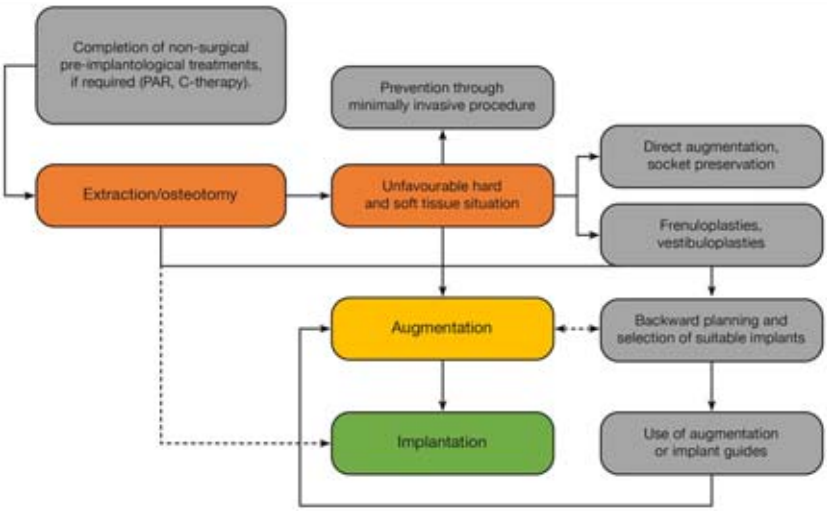

Figure 1 Basic strategies to reduce the peri-implant risk before and during implant placement.

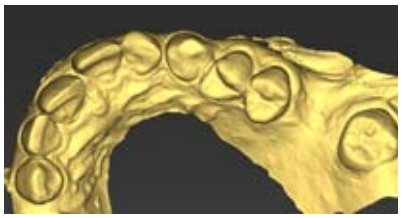

Figure 2a 3D data set of a switching gap in region 26 after direct intraoral scan.

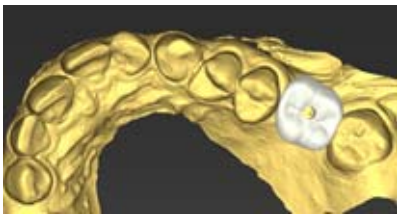

Figure 2b Virtual set-up of a prefabricated planning tooth 26 in the present 3D data set.

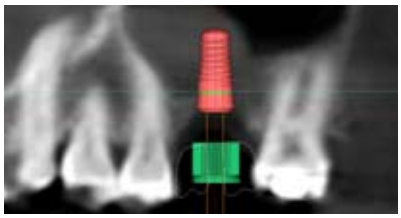

Figure 2c Sectional view from planning DVT (before pre-implantological measures) with virtually positioned implant 26, superimposed virtually positioned tooth and virtual drill sleeve. Here it is clear that a sinus lift is required before implant placement.

terms of implant prosthetics, the ideal implant position depends on the expected load from the denture and the available space. In particular, the expected load plays a prominent role in connection with the desired ideal long-term stability, as the ideal force distribution via the denture and the implant into the bone can only take place if the acting force has a direct effect in the implant axis and the implant has been correctly selected in terms of shape and diameter. In addition, it is essential to consider aspects of subsequent hygiene capability.

Due to the individual anatomical conditions of each patient, ideal conditions can only be found in extremely rare cases, so that in almost all cases the "ideal" implant position means the best implant position for the individual patient. Kalra et al. point out in their paper that optimal positioning taking into account biomechanical, masticatory, esthetic and phonetic aspects is a prerequisite for an optimal implant restoration [16]. The design of the subsequent prosthesis must therefore be determined before the actual implant placement. The following applies: the more precisely the planning corresponds to the subsequent restoration, the more information can be included in the implant planning. It is important to remember that not only the position and angulation of the implant play a role. According to Yi et al., the selected implant diameters with the resulting emergence angles and emergence profiles also have a significant influence on the development of peri-implant inflammation and thus on the long-term success of the restoration [28].

The influence of the final design of the prosthetic restoration on the risk of peri-implant inflammation is also an important aspect. This topic is the subject of another article in this issue and will therefore not be considered in depth below.

The basic procedure of backward planning is briefly described below using 2 examples: In the first example, a switching gap in the maxilla at position 26 is to be restored with an implant-supported single crown (Fig. 2a–e). A DVT image is taken to evaluate the bony structures and the maxillary sinus. The subsequent crown is clearly predetermined by the extent of the gap and the position of the antagonists. In this case, therefore, a virtual tooth set-up on the computer in suitable software is sufficient if required, which is then used for the initial virtual positioning of the implant. A three-dimensional data set of the clinical situation is required for the fabrication of the drilling template. This can either be obtained by scanning a situation model, or intra-oral scanning systems can be used for direct data acquisition. By merging the planning data and the model data set, all relevant information is available for the fabrication of the surgical guide, e.g. in 3D printing.

In the second example, a patient with a cleft jaw in the maxilla is to be restored with an implant-supported complete denture. No old denture is available. In this case, the subsequent position of the teeth and the volumes of the denture bases must first be determined by means of jaw relation determinations and wax-up, analogously to the procedure in conventional complete denture prosthetics. After the try-in on the patient, the wax-up and models can also be digitized.

If necessary, for example if the jaw relationship is unclear, the wax-ups can also be converted into radiopaque templates for a DVT scan using barium sulfate. Alternatively, in some cases it is also possible to use the palatal soft tissue situation in the maxilla to match the digitized model data sets with and without a wax-up as a reference in the implant planning software (Fig. 3).

In this example, too, all the relevant data for manufacturing the drilling templates are now available.

Today, digitally pre-planned implant positions and corresponding drilling templates can already achieve a particularly high predictability of the subsequent real implant position. Van de Wiehle et al. studied the transfer accuracy of template-guided implant placement and found deviations of the implant shoulder from the digitally planned position in both the vertical (0.5 ± 0.5 mm) and horizontal (0.9 ± 0.5 mm) directions [26]. Similar data have been found in other research groups, although maximum deviations in all spatial directions of up to 2 mm have also been observed [15, 27]. According to Ruppin et al., the accuracy of navigated implant placement depends on the quality and image resolution of the underlying 3D radiographic data set and the available bone [22]. Therefore, even with theoretically very good initial situations, slight deviations from the ideal implant position may ultimately occur during implant placement, e.g. in the maxilla due to the

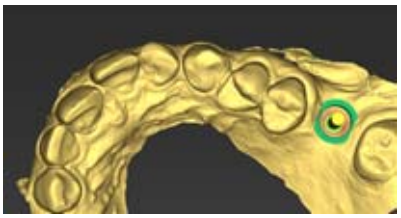

Figure 2d Projection of the virtually positioned implant onto the 3D dataset with additionally superimposed drill sleeve.

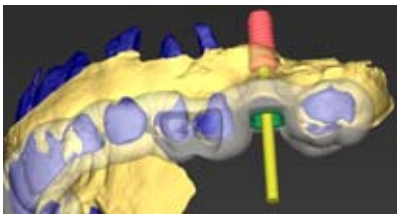

Figure 2e Teeth from DVT superimposed in the 3D dataset for correct matching of datasets with virtual implant, drill sleeve, implant axis and virtual drill guide.

lower density of cancellous bone (Fig. 4).

Pre-implant surgery and soft tissue management

The term pre-implant surgery covers all surgical procedures that serve to provide a biologically adequate hard-tissue implant site and adjacent soft-tissue site. This term must be distinguished from that of pre-prosthetic surgery. The latter includes surgical procedures that serve to improve the prosthetic bearing, especially in the era before the breakthrough of implant-supported dentures [11]. Typical procedures include lowering of the mouth floor, vestibuloplasty, and removal of slack ridges and ostoses [11].

A variety of different procedures exist to create a hard tissue implant site for subsequent implant placement. Frequently, reconstructive or augmentative procedures are divided into autologous, allogenic and xenogenic procedures according to the origin of the biomaterial used. While autologous bone, either microsurgically anastomosed or avascular, is considered the gold standard for reconstruction of continuity defects, allogeneic and xenogeneic materials can be used in addition to autologous procedures for circumscribed, local augmentation. In addition to their use in pure form, biomaterials can also be used in combination. For this purpose, the admixture of xenogeneic or allogeneic materials to autologous bone has proven successful. Intraoral donor sites for autologous bone, either as a block or in particulate form, include the retromolar region, the chin region, and for reconstruction in the esthetic region, the crista zygomatico-alveolaris [9]. For the sake of completeness, alveolar ridge distraction and sandwich osteoplasty should also be mentioned here, although both are indicated much less frequently in daily practice [1, 10].

In principle, bone grafts must be fixed in a positionally and rotationally stable manner to allow access by ingrowing vessels. Covering with a collagen membrane can improve the result and allows secondary wound healing without complications if dehiscence occurs.

Especially in the esthetically relevant anterior region or if large extraction sockets are expected, the possibility of socket preservation must be considered. In their review from 2019, Juodzbalys et al. have elaborated that esthetic, functional and risk-associated aspects should be used for decision-making in this context and presented a corresponding decision tree [14].

The use and success of allogeneic and xenogeneic materials in pre-implantological surgery have already been demonstrated scientifically in large numbers. For this reason, many of these bone substitutes or biomaterials are established as standard augmentative procedures for many indications. While the interaction between the implant surface and the hard tissue bearing is crucial for the initial osseointegration of dental implants, the maintenance or generation of an adequate soft tissue situation around the implant is seen as a key factor for long-term success and for the prevention of peri-implant diseases. In their systematic review, Pranskunas et al. found that the absence of keratinized attached gingiva in the implant site is necessary to improve hygiene and reduce the risk of peri-implantitis [18]. For this reason, soft tissue interventions, often in the form of various free connective or mucosal grafts, are an integral part of current dental implantology [24]. Soft tissue grafting can be performed temporally before, during, and after placement of a dental implant [25]. The goal of all procedures is basically to create a hem of 2 mm of keratinized mucosa circularly around the implant [20].

Navigated, template-guided implantation

The targeted use of digital image analysis enables precise prediction for pre-implant bone augmentation and the creation of computer-assisted drill guides with pinpoint implementation of both bone augmentation and implant placement [8, 9].

In this context, too, the terms navigation and template-guided implantation should be handled carefully, as they are often erroneously used synonymously. The basic prerequisite for both procedures is a 3D data set (DVT/CT) with a slice thickness <1 mm. Navigation is a real-time scanning procedure. For this purpose, (drilling) instruments can be provided with reference markers, registered and used for real-time scanning – so-called real-time navigation. In dental implantology, the implant drill can thus be registered ("tracked"), and the three-dimensional movement of the instrument can be followed in real time on the screen [29, 30, 31]. Three-dimensional control of the drill instrument is freely in the hands of the surgeon. The vector and length of the drill bit can be planned virtually, but are not fixed in a template. In contrast, in template-guided implantation ("guided surgery") – depending on the nature of the template – implant position, length and vector are encoded. It usually does not include a real-time component, as the implant hole is coded in all dimensions in the template. Theoretically, both methods could be combined, but this would not result in any additional gain in information and safety. It has been

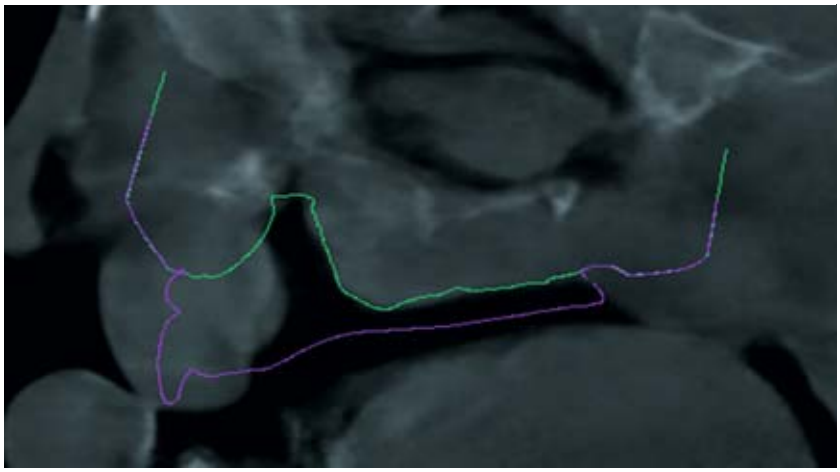

Figure 3 Data sets from DVT and model scan (green line) and wax-up (violet line) superimposed on the basis of the mucosa reference. It is particularly clear which soft tissue support can be expected from the anterior set-up.

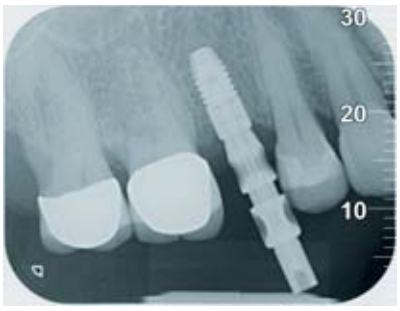

Fig. 1–4: P.-C. Pott

Figure 4 Implant in region 15. The screwed-in impression post shows a slight mesial angulation of the implant.

demonstrated in numerous scientific publications that guided and navigated implant placement is superior to freehand implant placement for achieving the preoperatively virtually planned implant position [13]. In addition, both procedures provide additional safety to protect important adjacent anatomical structures. It seems conceivable that precise implant positioning in accordance with the preliminary planning can also reduce the probability of occurrence of peri-implant diseases, but this has not yet been proven beyond doubt.

Brief overview of current relevant literature

Overall, the literature on surgical prevention in particular is still very limited. Although there are many articles on surgical therapy of peri-implant diseases, there are only few on direct prevention of peri-implantitis. This brief review intentionally includes only articles from the past 5 years, as the authors believe that current literature is relevant for new patient care.

A PubMed search of current literature from the past 5 years on the topic of surgical prevention of peri-implant inflammation with the search term "surgical prevention of peri-implantitis" resulted in a total of 98 hits. After independent review of the hit list, 95 articles were excluded based on the titles that dealt with the therapy of peri-implant inflammation and not with its prevention.

After reviewing the abstracts, a total of 3 articles remained, plus one additional article from the relevant secondary literature, which have been included in the following brief overview.

Romanos et al. describe that, in addition to implant-prosthetic components, trauma during surgically invasive treatment, the choice of the correct implant diameter and the misplacement of implants have an influence on the formation of biofilm and on the processes of bone remodeling. Biological aspects, such as sufficient bone volume and an adequate attached mucosa in the surgical site, also play prominent roles [21].

Plonka et al. have dealt with vertical ridge augmentation and described a decision tree for augmentation heights of less than 4 mm, between 4 and 6 mm, and of more than 6 mm. Plonka's group also emphasizes that anatomical, clinical, and patient-specific factors influence treatment success [17]. Fu and Wang already dealt with horizontal bone augmentations in 2011 and found that the thickness of the soft tissue, position and shape of the alveolar ridge and the availability of autogenous bone in the augmentation area have an influence on the augmentation success [5]. In their paper published in 2020, Geisinger et al. also emphasize the particular importance of patient-centered and evidence-based implant planning for long-term treatment success. Above all, patient-specific risk factors must be taken into account in the therapy finding process. In particular, Geisinger et al. cite underlying systemic diseases, systemic medications, smoking, existing periodontal disease, effectiveness of plaque control, quality and quantity of relevant soft tissue, and individual anatomical conditions as influencing factors [6]. All the groups of authors cited here agree that long-term successful implant treatment requires targeted planning of the implant placement, taking into account patient-specific anatomical as well as anamnestic conditions.

Conclusion

Finally, the question posed at the beginning "Is there an ideal implant position and how can it be found?" will be answered.

Taking into account the patient-specific risk factors, the individual hard and soft tissue situation, the requirements for high esthetics, long-term functionality and the associated good hygiene, it can be summarized that the "ideal implant position" must be understood as a patient-specific optimum. This optimum can be achieved today with a high degree of planning reliability by means of a complete clinical assessment taking into account the aspects listed in this article with regard to pre-implantological surgical measures and ad-

equate backward planning. Nevertheless, the risk of peri-implant infections cannot be completely eliminated in the course of treatment, but can only be reduced.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

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Patient-related risk factors for peri-implantitis and pre-implant treatment

Introduction: Peri-implantitis represents a major complication for the long-term preservation of dental implants and is often attributable to the combined effect of risk factors. This review aims to present patient-related risk factors that are linked to peri-implantitis and to discuss possible solutions in terms of a pre-implant therapy.

Material and methods: While implant characteristics and surgical techniques are patient-independent risk factors for peri-implantitis, patient-related factors may also potentially contribute to an increased risk of developing peri-implantitis. The most commonly discussed factors include patient age, medication and other medical treatments, existing periodontitis, plaque and limited oral hygiene, patient compliance related to supportive implant therapy, lack of attached gingiva, smoking, diet, diabetes, and patient genetics.

Conclusion: Whereas patient age was not found to diminish implant survival and the factor genetics is currently considered to be unpredictable, potential influencing measures could be identified for the other risk factors. These include a comprehensive anamnesis and diagnosis, attention to contraindications (e.g. i.v. antiresorptives, patients receiving radiotherapy and smoking simultaneously), treatment of existing periodontitis, smoking cessation, adequate adjustment of HbA_{1c} values in diabetics, dietary counseling, plaque reduction, attention to and creation of attached gingiva and sufficient hard tissue as well as offering a well-structured supportive implant therapy.

Keywords: diabetes; diet; implant aftercare; peri-implantitis; plaque; pre-implant treatment; risk factors; smoking

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Introduction

Dental implant placement is nowadays a routinely and widely used procedure for the replacement of teeth, which has the advantage of conserving the adjacent teeth. It is estimated that around 12 million implants are placed annually worldwide [1]. Implants show survival rates of over 90% in 10-year follow-up studies [29, 44]. However, one of the main complications that limits the long-term success of implants is peri-implantitis. It affects an average 22% of implants and it is not treatable predictably using current methods [7, 14]. For this reason, the prevention of peri-implantitis is of critical importance.

While the choice of implant materials and surgical techniques are two factors that the dental team can directly influence in the prevention of peri-implantitis, patients themselves harbor factors for the development of peri-implantitis, namely the interplay between biofilm and the immunological response (Figure 1). Similar to the "host-mediated dysbiosis" described in the etiology of periodontitis, both the immune system as well as the patient's behavior play significant roles. Furthermore, it is believed that the inflammatory process of peri-implant mucositis is a precursor stage to peri-implantitis, which is then accompanied by irreversible bone resorption [51]. Taking into account the varying influences that can lead to peri-implantitis, it comes as no surprise that a recent study was able to demonstrate strong interindividual differences in the immunohistological response associated with peri-implantitis (at the time of explantation) [12]. The risk factors of peri-implantitis can exert both a strong localized influence (such as plaque and attached gingiva), as well as a strong systemic effect (such as medications, age, smoking).

In order to identify patient-related risk factors that are involved in triggering such individually varying immune responses, it may be helpful to ask how tooth loss occurred in the first place before implants are placed. Apart from trauma and tumor-related reasons, it can be assumed that either genetic and/or behavioral factors (resulting in caries and periodontitis) have resulted in tooth loss. While the development of caries is primarily determined by the increased consumption of processed carbohydrates (such as sugar, sweets, soft drinks, juices), on the one hand, and fluoridation through oral hygiene measures, on the other, other immunomodulatory risk factors play a role in the etiology of periodontitis [31, 47]. Besides the special factor, namely plaque, behaviors such as smoking, pro-inflammatory diets, physical inactivity, and stress augment a possible genetic predisposition [9, 13, 30, 47, 50, 71]. Even though many of these risk factors for periodontitis have been substantiated with robust evidence, they are poorly documented in the context of peri-implant inflammation in the current scientific debate. In this respect, in what follows, the various peri-implant risk factors will be presented in terms of their varying importance and preventive options will then be suggested, where possible.

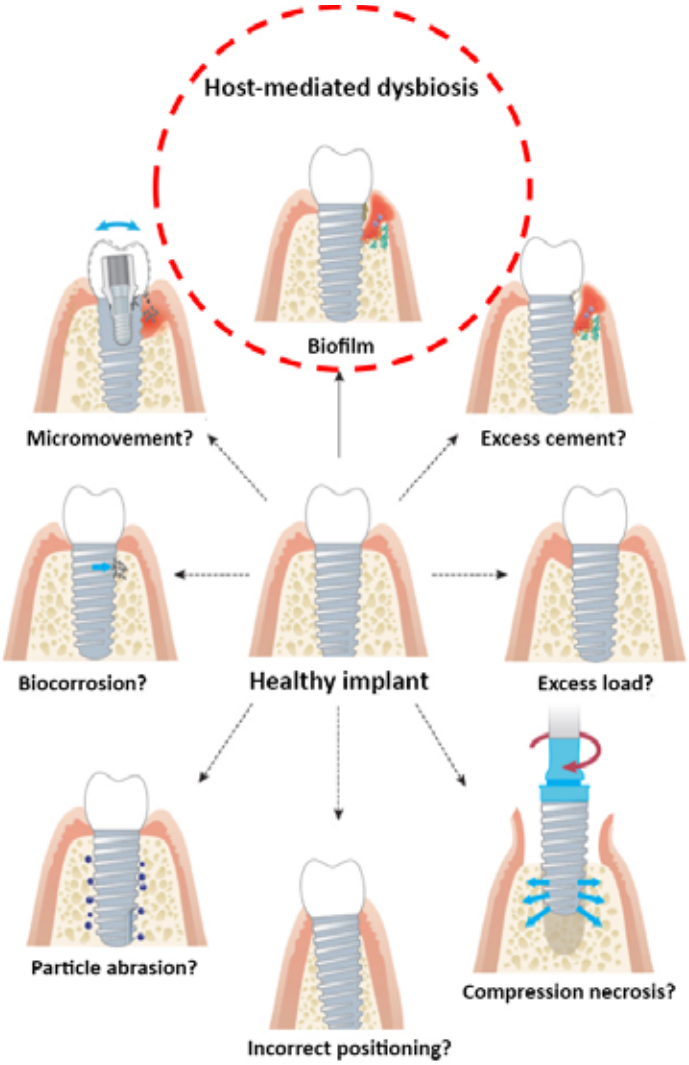

Figure 1 Multifactorial etiology of peri-implant bone resorption. Besides implant-related and surgery-related factors, biofilm is a patient-related risk factor in the interplay between immunology and plaque control ("host-mediated dysbiosis"). Modified according to Fretwurst et al. [19, 21].

Patient-related risk factors and recommended pre-implant treatment measures

Factor age

Aging is associated with many immunomodulatory processes that, collectively, can result in an increased tendency for inflammation. In this con-

text, the term "inflammaging" is also used [18]. Nevertheless, based on a systematic review, chronological age alone does not seem to be a risk factor for implant survival over a period of 1–5 years [57]. However, it must be taken into account that in quite a few studies, a more or less arbitrary age threshold (e.g. definition of "old" at >75 years) was used, and long-term studies regarding an association between age and peri-implant bone resorption or peri-implantitis are still missing [21]. Careful consideration should also be given to the fact that, with advancing age, the number of underlying diseases and prescribed drugs increases, too, and this may likewise have an impact on implant success. Last but not least, genetics, environmental and socioeconomic conditions as well as lifestyle and general health influence the aging process; this can lead to interindividual differences between chronological and biological age [37, 48]. The value of chronological age as a risk factor alone is therefore questionable.
Recommended measures: According to current data, chronological age is not a risk factor for peri-implantitis. For older patients, possible polypharmacy should be carefully considered.

Factor drugs and other medical therapies

The effects of drugs (and their interactions) on implant survival or success are poorly investigated [10, 21]. Antiresorptive drugs are an exception: two systematic reviews have demonstrated that implant survival rates in patients who take low-dose (oral) bisphosphonates (BP) or antiresorptive drugs (denosumab: Prolia®, Xgeva®) are the same as in healthy patients who do not take such drugs [57, 63]. However, the risk of MRONJ (medication-related osteonecrosis of the jaw) must be considered and prophylactic antibiotics are recommended. High-dose BP and antibody therapy lead to the highest incidence of MRONJ, and consequently, implant therapy is not recommended in this patient group at present [54, 64]. For risk evalulation prior to implant treatment, the DGI's plan routing slip "Risiko-Evaluation bei antiresorptiver Therapie vor Implantation" is recommended (https://www.dginet.de/documents/10164/1523441/Laufzettel_Farbe+_+2.pdf/0bee9d86–22d7–4121-ad85-f531ab1d6c9e) or the corresponding guidelines (S3 Guideline "Antiresorptiva-assoziierte Kiefernekrosen"/"Antiresorptive drugs-associated necrosis of the jaw" (AR-ONJ) and the S3 Guideline "Zahnimplantate bei medikamentöser Behandlung mit Knochenantiresorptiva (inkl. Bisphosphonate)"/"Dental implants during drug treatment with bone antiresorptives (incl. bisphosphonates)"). For patients with peri-implantitis who receive antiresorptive drugs, no treatment schemes are available [21, 68].

Furthermore, omeprazole (proton pump inhibitor) and sertraline (selective serotonin reuptake inhibitor) are currently discussed as "potential" risk factors based on a low level of evidence [10]. Levothyroxine and simvastatin, which are also among the 20 most commonly prescribed drugs, cannot be evaluated due to the lack of data. Moreover, it is unclear whether anticoagulants and the new direct oral anticoagulants are a risk factor for implant survival [25]. The increased postoperative bleeding risk should be taken into consideration in this patient group [6, 40].

A systematic review examining immunosuppression and implant survival for 24-month follow-up periods reported a median implant survival of 93.1% in HIV patients, 98.8% in patients receiving chemotherapy, 88.75% in patients with autoimmune diseases, and 100% in patients following organ transplantation [16].

In addition to drugs, other medical treatments such as radiotherapy can influence implant survival. In this regard, it is important to consider the risk of osteonecrosis. Implant survival tends to be lower in patients who have received radiotherapy as compared to healthy patients, but there is no reliable data on peri-implantitis [58]. An absolute contraindication is the condition after radiotherapy in smoking patients. According to the current guideline, the time interval between radiotherapy and implant placement has no effect on implant prognosis [56]. However, a waiting period of 6–12 months after radiotherapy is recommended in order to allow early and delayed radiation effects, especially on the oral soft tissues, to subside. Up to 6 months should be waited for implant healing to occur. Perioperative systemic antiinfective prophylaxis (e.g. amoxicillin, clindamycin) should be given according to the shared statement of the DGZMK and DEGRO.
R**ecommended measures:** Implant treatment in patients who take oral BP and have a low-risk profile is possible under antibiotic prophylaxis (prolonged perioperative systemic antibiotic administration with, for example, 1 g amoxicillin 1–1–1 or 0.6 g clindamycin 1–1–1). The risk of MRONJ should be considered. Implant procedures are contraindicated under i.v. BP therapy. Augmentative procedures should generally be avoided under BP therapy. Immunosuppressed patients usually do not show poorer implant survival than healthy patients during follow-up periods of up to 2 years. However, implant treatment should be carefully considered in these patients. Perioperative antibiotic prophylaxis is strongly recommended in this patient group. No evidence-based statements can be made regarding implant placement in patients who have undergone radiotherapy. Implant placement should be delayed for 6–12 months after irradiation.

Factor periodontitis

Apart from the fact that periodontitis is considered the major cause of tooth loss from advanced adulthood, the presence of periodontitis can be understood as a sign of immune modulation [4]. In this respect, it does not seem surprising that existing periodontitis is likewise a risk factor for the development of peri-implantitis [34, 41]. This is especially true in cases where there is a strong genetic component in the development of periodontitis from a young age (formerly classified as "aggressive periodontitis", now grade C with possibly a molar-incisive pattern). A prospective cohort study which examined 35 patients with "generalized aggressive periodontitis"

found a 5-fold increased risk of early implant loss, a 3-fold increased risk of peri-implant mucositis, and a 14-fold increased risk of peri-implantitis compared to 18 periodontally healthy patients who were treated with implants [66]. This result was also confirmed in a subsequent meta-analysis [67]. Pre-existing periodontitis seems to be a risk factor for the development of peri-implantitis in older patients, too [34]. However, this risk is greatly reduced if patients who are affected by periodontitis receive adequate periodontal treatment in advance and are commited to participate in a recall system [27, 41].

Recommended measures: At least the periodontal screening index (PSI) must be recorded prior to implant treatment. If PSI values 3 are recorded in 2 sextants, systematic periodontal therapy is indicated prior to implant placement [3]. Optimally, as a prerequisitve for implant treatment, increased probing depths (>4 mm) should no longer be recorded in the re-evaluation of the periodontal treatment outcome [27]. Patients with grade C periodontitis should be informed about an increased risk of peri-implantitis.

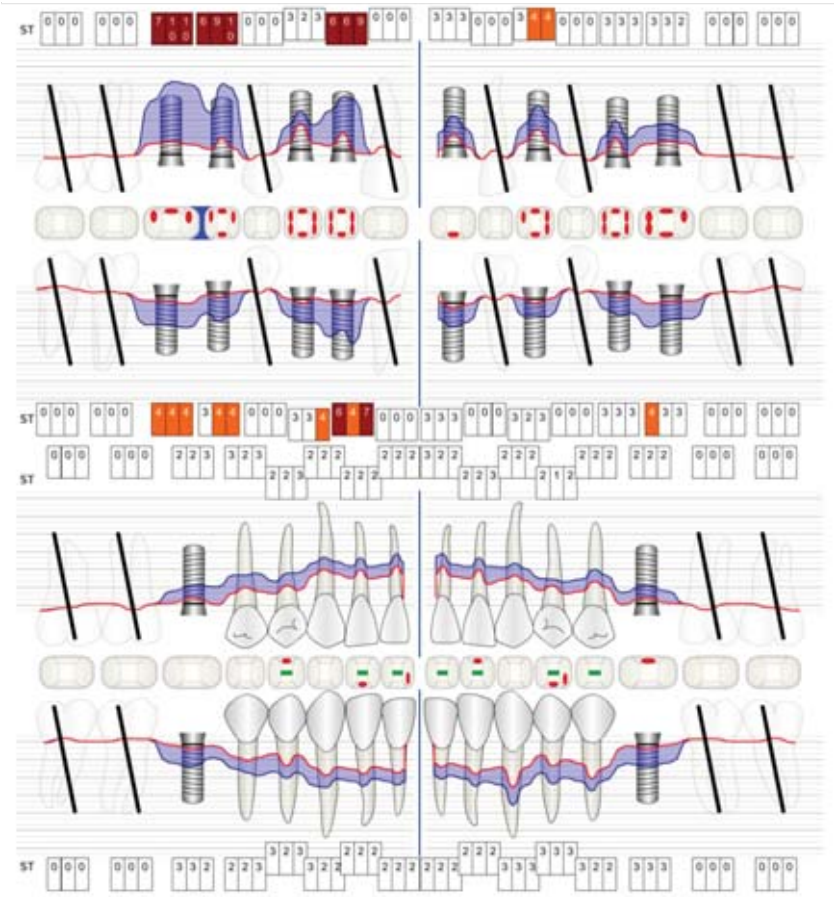

Figure 2 Implant and periodontal status (created using Parostatus.de©) of a 56-year-old smoker with peri-implantitis in regions 16, 15, 12 and peri-implant mucositis in regions 13, 23 and 26.

Factor plaque

Plaque is one of the best-studied factors that is known to promote gingival and mucosal inflammation, not only around teeth, but also around implants [28, 51]. However, owing to the ubiquitous presence of biofilm in the oral cavity, this link has not been unequivocally proven as an etiologic factor [11]. In contrast, plaque control has been established as an evidence-based measure to control peri-implant tissue inflammation [28].

Recommended measures: Professional tooth cleaning and encouraging home-based plaque control. Before implant placement, professional tooth cleaning should be performed and adequate home-based plaque control should be established. This includes the collection of the plaque and bleeding indices and advice regarding which oral hygiene aids are best suited for the patient. Repeated follow-up checks are advisable when lots of plaque and severe gingivitis is present.

Factor compliance/recall behavior

Studies investigating periodontal disease have substantiated the paramount importance of patient compliance to participate in supportive periodontal therapy; similarly, an increasing number of studies have appeared in recent years that support the importance of compliance to participate for long-term implant survival and prevention of peri-implantitis [17, 23]. A retrospective study over a 7-year period was able to determine a 4.25-fold higher incidence of peri-implantitis when only irregular participation in the program of supportive implant therapy was recorded [23]. When a well-structured, supportive implant therapy program was offered, participant compliance was determined at over 60 % [42].

Recommended measures: Patient inclusion in supportive implant therapy. A well-structured therapy program includes regular, repeated clinical examinations of implants, the recording of probing depths and possible bleeding on probing as well as professional mechanical plaque reduction. It also includes patient motivation and instruction on oral hygiene at home and the continuous minimization of possible risk factors.

Factor soft and hard tissue

In principle, soft and hard tissues diagnosis is required prior to implant treatment. In terms of soft tissue, attention should be paid to the quantity of attached gingiva, the gingival phenotype (thin/thick) and the presence of any pathological mucosal changes. Current literature suggests that >2 mm of attached gingiva is needed at the peri-implant site [5, 36]. Although the importance of the attached gingiva with regard to the prevention of peri-implant inflammation

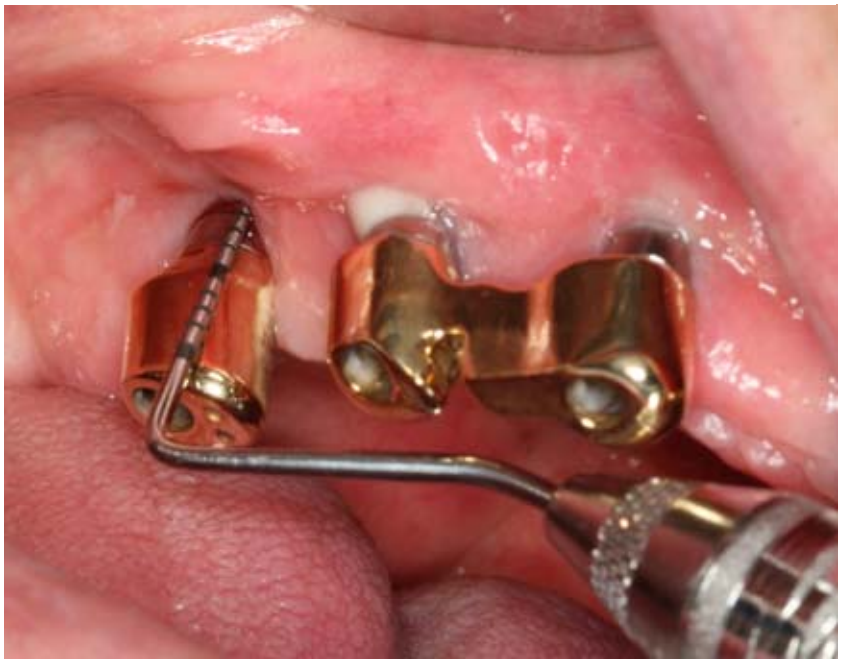

Fig. 1–3: J. P. Wölber

Figure 3 Clinical image showing the outflow of pus at site 15 after probing in the same smoking patient.

has long been discussed [7], its importance has been emphasized in more recent literature [26, 33, 35]. This may also affect the subsequent treatment of peri-implantitis [65].

The position of the adjacent and antagonist teeth (dimension of the subsequent prosthetic superstructure) as well as the jaw relation should be considered during implant planning.

For the assessment of hard tissue, imaging diagnostics are needed prior to implant treatment in order to visualize potential risk structures. Orthopantomograms (OPG) as well as a cone-beam CT (CBCT) represent imaging options for the visualization of hard tissue. With regard to the indication of a CBCT prior to implant treatment, reference is made here to the S2k Guideline [59]. Currently, 1 mm, or preferably 2 mm, of peri-implant bone is required [8].

Recommended measures: Detailed diagnosis of soft and hard tissues prior to implant treatment. In cases of insufficient fixed gingiva, its creation, for example, by means of connective tissue transplantation from the palate is a recommended preventive measure after implant placement. Insufficient fixed gingiva can also be augmented by means of vestibuloplasty with a free mucosa graft. However, it is not clear which dimension (width, thickness) of fixed gingiva leads to a lower prevalence of peri-implantitis. Literature currently states that >2 mm of fixed, peri-implant gingiva is needed [5, 36]. Concerning hard tissue, at least 1–2 mm of peri-implant bone should be present.

Factor smoking

Smoking has been recognized as a risk factor in the new classification of periodontal and peri-implant diseases and conditions [7, 28]. An increased risk (odds ratio 5.89) for the development of peri-implantitis was found in smokers according to a cohort study performed in a practice-based setting [52]. In a long-term study, smoking was correlated with peri-implant mucositis, bone resorption and peri-implantitis [53]. Figure 2 shows periodontal and peri-implant findings in a female smoker with clinical release of pus after probing in regio 15 (Figure 3).

Recommended measures: Smoking cessation and/or smoking withdrawal is advisable. For the prevention of peri-implantitis, a possible smoking status should be recorded in the anamnesis and smokers should be advised to stop smoking [70]. If professional help is not offered for quitting smoking in the practice setting, a third party health psychologist or physician should be consulted. Radiation in the head and neck region in patients who (continue to) smoke is an absolute contraindication for implants due to the increased risk of osteoradionecrosis.

Factor diet

Though the relationship between diet and caries has been scientifically confirmed for a long time, in recent decades, diet has become an increasingly important etiological factor in the development of gingivitis and periodontitis. [47]. The most problematic macronutrients in this context are processed carbohydrates (e.g. sugar, sweets, juices, soft drinks). Whereas these substances are found only in association with anti-inflammatory dietary fibers and antioxidants in nature, they represent an excessively consumed substance in the dietary behavior of Homo sapiens, with approximately 35 kilograms of sugar being consumed per capita per year [15]. The consumption of sugar promotes both caries and gingivitis and it is associated with the presence of periodontitis [30, 31, 39, 71]. In terms of peri-implantitis, initial studies actually show both a plaque-promoting effect of sugar consumption at implant sites as well as an association with peri-implant mucositis and peri-implantitis [62, 69]. Experimental animal studies have also used processed, high-carbohydrate diets to provoke corresponding peri-implant inflammation [61].

Although several anti-inflamatory and pro-inflammatory dietary factors have now been identified in relation to periodontal inflammation [71], hardly any studies exist in the field of implantology. However, the few studies that are available are consistent with evidence deriving from the field of periodontology, e.g. that secondary plant compounds may have an anti-inflammatory effect on peri-implant inflammation [24]. Furthermore, in the field of micronutrients, the regulation of vitamin D is also of interest. According to recent studies, vitamin D levels appear to have an influence on peri-im-

plant osseointegration, and low serum vitamin D levels can also be associated with cases of early implant loss [19, 22, 45]. However, randomized, controlled intervention studies are lacking in this domain in order to provide causal evidence for this relationship. In the field of periodontal therapy, a randomized, controlled intervention study found clinical benefits of adjuvant vitamin D administration in patients with low serum vitamin D levels (<30 ng/ml) [49].

Recommended measures: Dietary counseling. Based on the available evidence, the patient should be advised to reduce or avoid processed carbohydrates (such as sugar, sweets, white flour, juices, soft drinks).

Previous to implant treatment, in cases where tooth loss occurred as a result of periodontitis, a plant-based whole food diet with possible supplementation of vitamin B12, vitamin D, and omega-3 fatty acids may be advisable [71]. This nutritional formula in turn has a positive influence on the whole body. In patients at high risk, serological testing can be considered for a more accurate reflection of their nutritional and micronutrient status. Indicative factors may include cholesterol, HbA_{1c}, and vitamin D. If no dietary counseling is offered in the dental practice, cooperation with appropriate medical colleagues and/or nutritionists is recommended.

Factor diabetes

Although the association between periodontitis and diabetes is well elucidated and considered highly relevant [55], the assoication between diabetes and peri-implant inflammation has not been fully elucidated [28]. It is important to consider the HbA_{1c} level, which reflects the blood glucose level in the last 2 months, because diabetics with well-controlled HbA_{1c} levels do not seem to have an increased risk of peri-implantitis [60]. One study found diabetes to be a stronger influencing factor than smoking in cases where HbA_{1c} values were not well controlled [2]. However, according to systematic reviews, diabetes mellitus does not seem to be a risk factor for short-term (≤5 years) implant survival [44]. But no standardised protocols are available regarding appropriate perioperative treatment (e.g. perioperative antibiotic therapy) and wound closure. Moreover, limited evidence exists in literature relating to bone grafting success and progressive loading protocols in patients with diabetes [21]. Complex surgical procedures should therefore be carefully considered, especially in diabetic patients.

Recommended measures: Serological control of the HbA_{1c} value in diabetics. In cases of abnormal values, the consultation with the general physician and the improvement of medication by the general physician/diabetologist as well as further dietary counseling is advisable prior to implant treatment. Complex surgical interventions should be carefully considered in diabetics, as the data on long-term success is insufficient.

Factor	Recommendation
Factor age	Chronological age is not a risk factor according to current data. Polypharmacy in the age group should be considered.
Drugs and other medical therapies	Implantation under oral BP therapy with a low risk profile is possible under antibiotic shielding. Implantological procedures under i.v. BP therapy are contraindicated. Augmentative procedures should generally be avoided under BP therapy. Implantation in immunocompromised patients should be carefully considered; antibiotic shielding is strongly recommended. Implantation after radiatio in the head and neck region is possible as long as there is no nicotine use.
Periodontitis	When a PSI of ≥3 at ≥2 sextants is detected, systematic periodontal therapy should be initiated prior to implant placement. After periodontal therapy, increased probing depths >4 mm should no longer be present.
Plaque	Professional dental cleaning and promotion of home plaque control.
Adherence	Inclusion in a program of supportive implant therapy (including clinical examination and professional mechanical plaque reduction, motivation and instruction in home oral hygiene, and continuous minimization of possible risk factors).
Hard and soft tissue	Basic clinical and radiological diagnostics. Establishment or creation of sufficient bone supply. Creation of attached gingiva after implantation.
Smoking	Smoking cessation recommendation. Offer of professional smoking cessation (by the practice or professional providers).
Nutrition	Recommendation to avoid processed carbohydrates (such as sugar, sweets, juices, soft drinks). In patients with tooth loss due to periodontitis, a plant-based whole food diet with possible supplementation of vitamin B12, vitamin D and omega-3 fatty acids may be recommended.
Diabetes	Serological control of the HbA_{1c} value in diabetics. In case of an imbalance, consultation with the general practitioner and improvement of the medication pre-implantologically via diabetology and nutritional counseling. Careful consideration of complex surgical procedures in diabetics.
Genetics	Genetic, microbiological or immunological diagnostics are currently not recommended due to lack of informative value.

Table 1 Patient-related risk factors – pre-implant checklist
Table 1: J. P. Wölber, T. Fretwurst

Factor genetics

The genetics of the patient is a fundamental factor that still cannot be influenced in practice, except for findings in epigenetics that suggest the modifiability of the effect of genes [43]. Although various genes have been associated with periodontitis in genome-wide association studies (GWAS) in the field of periodontology, they have not been well documented for peri-implantitis [46]. Interleukin-1 gene polymorphism has long been considered a risk factor for peri-implantitis in scientific literature. However, on the basis of the current heterogeneous study results, no recommended course of action for diagnosis can be derived [32, 38].

Recommended measures: At present, genetic, microbiological or immunological diagnostic tests (e.g. cytokines and biomarkers) in the gingival sulcus fluid of adjacent teeth, or existing implants, cannot be recommended due to a lack of validity with regard to implant success/risk of peri-implantitis [20].

Conclusions

According to the evidence presented, a variety of measures can be implemented to lower the risk of peri-implant inflammation. These include a comprehensive anamnesis and diagnosis, attention to contraindications (e.g., i.v. antiresorptives), treatment of existing periodontitis, cessation of smoking, adequate adjustment of HbA_{1c} values in diabetics, nutritional counseling, plaque reduction, creation of attached gingiva, and offering well-structured aftercare programs.

Table 1 provides a possible workflow checklist for pre-implant treatment.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

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