CLINICAL ORAL IMPLANTS RESEARCH

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Virtual implant planning in the edentulous maxilla: criteria for decision making of prosthesis design

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Abstract

Objectives: To evaluate prosthetic parameters in the edentulous anterior maxilla for decision making between fixed and removable implant prosthesis using virtual planning software.

Material and methods: CT- or DVT-scans of 43 patients (mean age 62 ± 8 years) with an edentulous maxilla were analyzed with the NobelGuide^{TM} software. Implants ($\geq$3.5 mm diameter, $\geq$10 mm length) were virtually placed in the optimal three-dimensional prosthetic position of all maxillary front teeth. Anatomical and prosthetic landmarks, including the cervical crown point (C-Point), the acrylic flange border (F-Point), and the implant-platform buccal-end (I-Point) were defined in each middle section to determine four measuring parameters: (1) acrylic flange height (FLHeight), (2) mucosal coverage (MucCov), (3) crown-Implant distance (CID) and (4) buccal prosthesis profile (ProsthProfile). Based on these parameters, all patients were assigned to one of three classes: (A) MucCov $\leq$ 0 mm and ProsthProfile $\geq 45^0$ allowing for fixed prosthesis, (B) MucCov = 0–5 mm and/or ProsthProfile = 30^0–45^0 probably allowing for fixed prosthesis, and (C) MucCov $\geq$ 5 mm and/or ProsthProfile $\leq$ 30^0 where removable prosthesis is favorable. Statistical analyses included descriptive methods and non-parametric tests.

Results: Mean values were for FLHeight 10.0 mm, MucCov 5.6 mm, CID 7.4 mm, and ProsthProfile 39.1^0. Seventy percent of patients fulfilled class C criteria (removable), 21% class B (probably fixed), and 2% class A (fixed), while in 7% (three patients) bone volume was insufficient for implant planning.

Conclusions: The proposed classification and virtual planning procedure simplify the decision-making process regarding type of prosthesis and increase predictability of esthetic treatment outcomes. It was demonstrated that in the majority of cases, the space between the prosthetic crown and implant platform had to be filled with prosthetic materials.

Atrophy of the maxillary jawbone as a result of complete tooth loss has a significant impact on treatment planning and implant prosthetics. According to Sadowsky (2007) an implant-supported fixed prosthesis can achieve optimal esthetics, phonetics, and hygiene access for patients with a minimally resorbed residual ridge. Therapy is significantly more complex in situations of moderate and especially advanced loss of soft and hard tissues (Henry 2002). Apart from tooth length, axis, color, and gingival exposure, oro-facial esthetics comprises also physiognomic aspects (Sutton et al. 2004). Facial support and natural lip mobility are crucial outcome parameters and important aspects that influence the decision between fixed and removable implant prostheses (Mericske-Stern et al. 2000; Neves et al. 2004). There are therefore two important parameters to consider: the emergence profile of the artificial tooth and the volume of hard and soft tissue that needs replacement.

The change in philosophy from "bone-driven" to "restoration-driven" implant dentistry was established with regard to the prosthetic reconstruction. The concept of virtual planning aims to optimize function and esthetics prior to implant placement (Garber 1995).

In this context, computer-assisted implant-planning software have significantly improved and provide clinicians excellent tools for pre-operative implant planning (Katsoulis et al. 2009). Careful and detailed treatment planning is enhanced (Ganz 2005).

Various systems for computer-guided template-based implant treatment are available on the market while high accuracy can only be achieved with well-fitting guides during

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CT scan and surgery (Schneider et al. 2009; Vasak et al. 2011). The goal is to ensure highly predictable and precise transfer of the planned three-dimensional (3D) implant position and angulation to the clinical procedures and implant placement. This is of particular importance in situations with only limited amounts of bone or critical proximity to limiting anatomical structures (Jung et al. 2009). In selected cases, a flapless procedure that is sometimes combined with an immediate implant-loading protocol has been suggested (van Steenberghe et al. 2005; Rubio Serrano et al. 2008). The jaw bone is often thin and atrophic in the anterior maxilla, which significantly affects the esthetic results of implant prostheses due to insufficient lip support (Flanagan 2005). Undesirable complications related to morphological and technical aspects may arise during the prosthetic phase or after delivery of the prosthesis (Salama et al. 2009). Variances in crown-to-implant positions relative to the required lip support create different scenarios for implant-supported full-arch prostheses.

In a recent Consensus report on biomechanics and risk management, it was concluded that further research on guided surgical protocols and critical evaluation in regards to esthetic outcomes and prosthetically related complications is needed (Sanz & Naert 2009). However, prosthetic parameters that may be evaluated virtually with an implant-planning software are not sufficiently examined and explored in their broad variety of applications. Even though computed technology facilitates precision of surgical steps, the selection of the appropriate treatment plan is complex and the predictability of the esthetic outcome is sometimes questionable (Calvani et al. 2007).

Therefore, this study determined anatomical and prosthetic landmarks on patient's CT or DVT and analyzed prosthetic parameters in the anterior region of the completely edentulous maxilla by means of computer-guided virtual implant planning.

The aim of this study was to identify and define anatomical and prosthetic criteria for prosthetically driven implant planning and for the decision-making process on the most appropriate prosthesis design in the anterior edentulous maxilla.

Material and methods

Patient data

Data of computed tomography or digital volume tomograms (CT or DVT) from 43 patients (24 female and 19 male) with edentulous maxillae were evaluated in this study. The mean patient age was 62 years (between 48 and 81 years). All of them were patients of record in the Department of Prosthodontics (School of Dental Medicine, University of Bern) and were examined during the period between January 2006 and December 2009 for implant-supported prostheses. This survey was part of a quality-control assessment during the dental examination and was approved by the institutional ethical review board. All patients had given written informed consent for their participation in the study. Exclusion criteria were patients with a history of palate or tuberosity surgery, presence of any stomatological disease that could affect soft and hard tissues, and patients taking medications (cyclosporin A, calcium channel blockers, phenytoin) that have an influence on soft-tissue quality (growth and hyperplasia). Smoking was not an excluding factor (11 patients were smokers). A panoramic radiograph was available for all patients before the treatment-planning phase.

Computer-assisted implant planning

Computer-assisted planning was applied (NobelGuide^{TM} software, Nobel Biocare, Gothenburg, Sweden) for detailed pre-surgical analysis and 3D virtual implant placement in relation to the prospective crown position. A well-fitting, functional, and pleasing denture or a prosthetic set-up that was optimized in respect to esthetic and functional parameters (Waliszewski 2005; Kamashita et al. 2006) were used as radiographic templates (Table 1). During the clinical try-in of the tooth set-up functional and esthetic aspects were evaluated with particular attention to the vertical dimension of occlusion, the facial support and the lip position (Figs 1 and 2). CT or DVT were obtained from all patients with the radiographic templates *in situ* (Loubele et al. 2006; Eggers et al. 2009). The templates were properly positioned during the radiographic procedure without any space between the radiographic template and the palatal mucosa. With the corresponding

Fig. 1. Extra-oral lateral view of a patient with an edentulous maxilla showing a wide naso-labial angle and insufficient lip-support.

Fig. 2. Same patient with a set-up *in situ* replacing the lost hard and soft tissues of the atrophic maxilla and thus supporting the upper lip.

Table 1. **Guidelines and checklist for a denture or set-up to be used in virtual implant planning**

Denture guidelines and check list
Denture satisfying the demands of support, stability and retention
Control of inter-jaw relation: space for prosthesis
Correct vertical dimension
Correct position of teeth (parallel to horizontal plane, correct inclination, form and size, vertical dental midline coincident with the facial midline)
Esthetically pleasant denture (lip and facial support, front teeth exposition, alignment, smile line, lip-line, gummy-smile)
Acceptable phonetics

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software, both hard and soft tissues were visualized in high-quality images.

Implants were virtually planned in the position of all front teeth to obtain measurements between the anticipated implant position and the prosthesis design in the anterior region, based on the following planning guidelines.

1. The implant had a minimum of 3.5 mm, preferably ≥4 mm diameter and a minimum of 10 mm intra-osseous length.
2. The virtual 3D implant position was determined in the most accurate location in reference to the tooth position in the radiographic template or denture.
3. The planned implant position and axis had to allow for palatal screw access and direct screw retention. Such an implant position allows for a prosthetic reconstruction that does not require either angled abutments or correction of inclination.
4. The bucco-palatal inclination of the implant axis was designed with respect to the residual alveolar bone and tooth position. With regard to point 2, the prosthetic determinant had a priority. While this may cause a more vertical implant angulation in relation to the buccally oriented jawbone, it prevents the implant shoulder being placed too far buccally, with a negative impact on esthetics. Otherwise, an implant position that does not respect the jawbone anatomy in all aspects may require additional surgical interventions. Minor local bone grafting (guided bone regeneration, GBR) was considered acceptable.

Prosthetic and anatomical landmarks

Cross sections of the CT scans in the middle of the maxillary incisors and canines as represented by the radiographic template were used to determine anatomic and prosthetic landmarks (Fig. 3). The occlusal plane was defined as parallel to the horizontal plane on the computer screen and served as a reference for the measurements. The following landmarks were determined as the reference points for the measurements in the middle of each anterior tooth (Fig. 4).

1. Central cervical point (C-Point).
2. Acrylic flange border (F-Point).
3. Implant platform buccal end (I-Point).

The following measurements were carried out, and reproducibility of the digitizing process was confirmed by means of double determination of all measurements by one

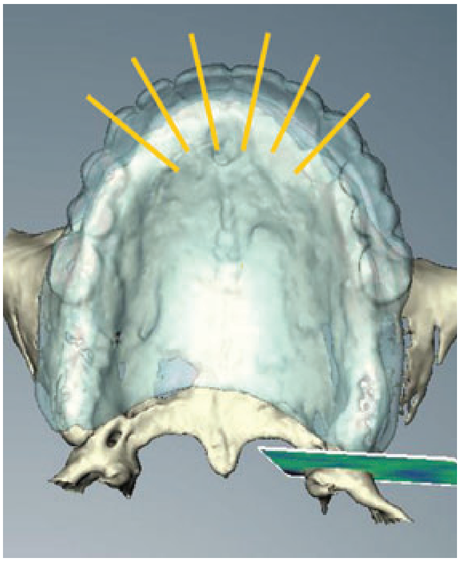

Fig. 3. Based on the set-up in the 3D reconstruction of the CT/DVT scan six cross sections were positioned in the middle of each anterior tooth.

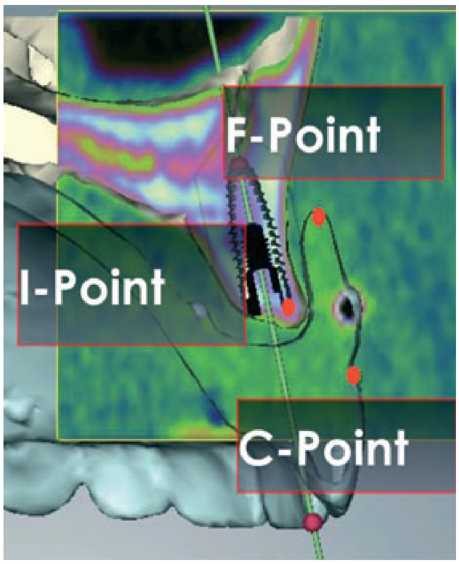

Fig. 4. Determination of the prosthetic and anatomical landmarks (reference points) in the cross sections. I-Point: The buccal end of the implant platform, F-Point: The end of the buccal acrylic flange, and C-Point: The central cervical point on each anterior tooth.

and the same examiner (intra-examiner reproducibility revealed excellent IICs = 0.85–0.96):

1. FLHeight: vertical distance from C-Point to F-Point, which is representative of the flange height (Fig. 5).
2. MucCov: vertical distance from I-Point to F-Point, representing the coverage of the mucosa from the acrylic flange above implant neck (Fig. 6).
3. CID: distance from C-Point to I-Point (Fig. 7). This measure is important for

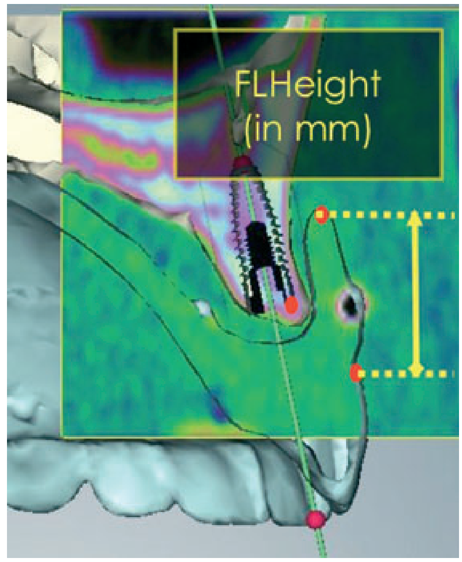

Fig. 5. Measured parameters in the cross sections: Total flange height.

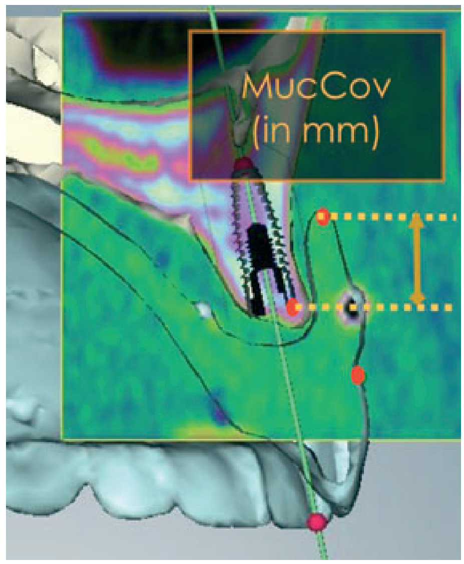

Fig. 6. Measured parameters in the cross sections: Acrylic flange covering buccal mucosa above the implant platform.

the emergence profile of prosthetic reconstructions and need for artificial soft tissue replacement.
4. ProsthProfile: buccal profile of the prosthesis as determined by the angle between the tangential line connecting C-Point, I-Point, and the horizontal plane (Fig. 8).

These measurements are representative for the parameters: emergence profile and tissue volume.

Classification for decision making

Based on the three landmarks (C-Point, F-Point, and I-Point), the following criteria for

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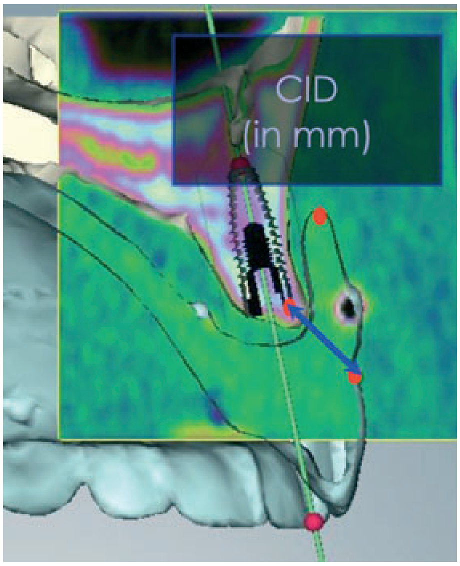

Fig. 7. Measured parameters in the cross sections: Space between prosthetic crown and implant platform.

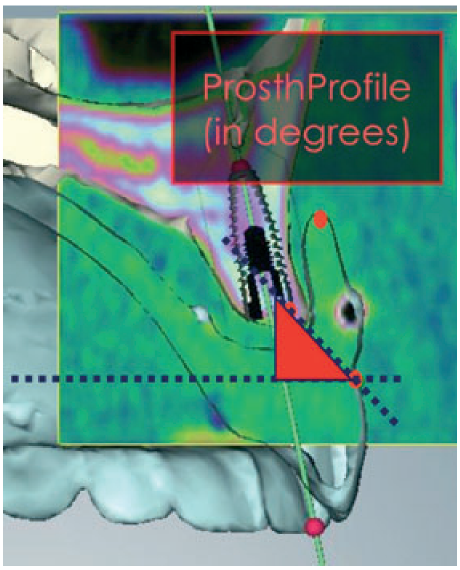

Fig. 8. Measured parameters in the cross sections: Angular aspect of buccal profile.

prosthetic decision making were established for MucCov and ProsthProfile.

1. A) MucCov ≤ 0 mm, B) MucCov 0-5 mm, and C) MucCov ≥ 5 mm
2. A) ProsthProfile ≥ 45 degrees, B) ProsthProfile 30–45 degrees, and B) ProsthProfile ≤ 30 degrees.

While MucCov was considered to provide information about esthetic needs, ProsthProfile was associated with hygiene, lip function, phonetics, cantilevers, and resulting biomechanics.

More specifically, MucCov A and B indicated situations where no (negative values) or moderate (0–5 mm) need for lip support was required. When the mucosal coverage exceeded 5 mm, lip support was strongly needed. ProsthProfile A and B were indicative for normal (≥45 degrees) or slightly altered (30–45 degrees) profile of the restoration enabling normal function.

ProsthProfile C less than 30 degrees was representative for a very steep transition from the crown to the implant that may cause functional problems (Jemt 1991; Schnitman 1999; Coachman et al. 2010).

The following classification for decision making was proposed (Table 2).

Class A: MucCov ≤ 0 mm and ProsthProfile ≥ 45 present a favorable situation for a fixed prosthesis with a crown design (Fig. 9).

Class B: MucCov 0–5 mm and/or ProsthProfile 30–45 degrees, sites may allow for a fixed prosthesis with hybrid design (Fig. 10).

Class C: MucCov ≥ 5 mm and/or ProsthProfile ≤ 30 degrees, a removable prosthesis with a buccal flange is advised (Fig. 11).

Statistical analysis

Statistical analyses were carried out with the SPSS software (SPSS 17.0, SPSS, Chicago, IL, USA). Descriptive statistics consisted of mean value, standard deviation, minimum, and maximum for all variables. Mann–Whitney *U*-test was used for the comparison between left and right side measurements and the comparison between genders. Chi-squared test was used for comparison of group proportion.

Results

Measurements for prosthetic and anatomical landmarks

There was no statistical difference between the left and right sides and therefore data were matched. Mean values were for FLHeight 10.0 mm, MucCov 5.6mm, CID 7.4 mm, and ProsthProfile 39.1 degrees. Table 3 presents values for FLHeight, MucCov, CID, and ProsthProfile in the positions of the central and lateral incisors as well as the canines.

A wide range of acrylic flange height was observed (3.5–17 mm). Measurements of ProsthProfile varied substantially between 0 and 89.7 degrees, particularly in lateral incisor and canine areas. Zero degrees were measured in sites where the cervical point of crown was positioned in the same horizontal plane and just in front of the implant platform, while maximum values around 90 degrees were associated with sites where the cervical part was positioned at a distance underneath the implant platform.

***Table 2.* Classification for decision making based on the proposed criteria**

Prosthesis Profile (ProsthProfile)	Mucosal Coverage (MucCov) 0mm	0-5mm	5mm
≥45 degrees	A Fixed prosthesis Crown design	B	C
30-45 degrees	B Probably fixed prosthesis Hybrid design	B Probably fixed prosthesis Hybrid design	C
≤30 degrees	C Removable overdenture or total prosthesis	C Removable overdenture or total prosthesis	C Removable overdenture or total prosthesis

Fig. 9. Fixed implant-supported prosthesis with no need for pink material in the cervical region (crown design).

Fig. 10. Fixed implant-supported prosthesis with artificial gingiva (hybrid design).

Fig. 11. Removable implant-supported prosthesis with extended labial flange (Removable OD).

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Classification for decision making

According to the proposed classification, 70% of the patients fulfilled class C criteria (removable OD), 21% class B (probably fixed prosthesis – hybrid design) and 2% class A criteria (fixed prosthesis – crown design). For three patients, implant planning could not be performed due to advanced horizontal and vertical atrophy of the ridge (Table 4).

Discussion

A primary aim of the present study was to define criteria for the analysis of the edentulous anterior maxilla and the relative position of the artificial teeth. These criteria are primarily related to the emergence profile of prosthetic crowns and the volume of hard and soft tissue to be replaced in the atrophic maxilla.

During the last years, systematical analyses were proposed to help the decision making for the treatment of the edentulous maxilla. Bedrossian et al. presented three factors (presence or absence of a composite defect, visibility or lack of the residual risk during clinical evaluation and quantity of available bone through radiographic evaluation) as the major guidelines for the type of maxillary implant-supported reconstruction (Bedrossian et al. 2008). Bidra and Agar presented a 3D analysis based on various esthetic concepts for implant planning in the edentulous maxilla (Bidra & Agar 2010; Bidra 2011). A classification of patients was proposed into four categories to help choose the appropriate design of a fixed prosthesis. In this classification, the prosthetic space decreases and complexity increases from Class I to Class IV requiring design changes of the prosthesis or surgical procedures to allow an esthetic fixed implant-supported prosthesis. Malo et al. in a pilot study presented a planning protocol for the rehabilitation of the edentulous maxilla. They remarked a limit of 45 degrees between implants and prosthesis for normal lip function. Authors focused that an increased angulation may compromise lip movement when smiling and may provide food entrapment in transition zone (Malo et al. 2008).

The same considerations for an appropriate design of artificial gingiva emergence profile was extensively analyzed in a recent three-part article (Coachman et al. 2009, 2010; Salama et al. 2009). A software that allowed for 3D simulation reported data on soft and hard tissue reconstruction in fixed partial prostheses for replacement of front teeth. The authors emphasized the role of virtual planning for a correct esthetic, hygienic, and functional result in the anterior maxilla.

In the present study, a similar philosophy of virtual analysis was applied to focus on prosthetic parameters that directly influence the decision-making process of a specific design in the cervico-apical area of a fixed or a removable reconstruction. While many patients request a fixed implant-supported restoration with a crown design, there may be a need for facial support with an acrylic flange even if implants can be placed in a proper position.

Definitely the desire of the patient is of major importance and should always be considered in combination with a detailed diagnostic examination. The prosthesis design in the edentulous maxilla should not be selected randomly or just on the basis of the patient's or the operator's preference. Zitzmann and Marinello proposed a treatment concept that enables the practitioner to choose the appropriate type of restoration in consultation with the patient before the surgical procedure has been initiated (Zitzmann & Marinello 2000a,b,c). The presented systematical analysis and the followed classification gives dentists the possibility to evaluate in detail the relationship of anatomical structures, implant position and teeth position and to explain specific aspects with the patient. Thus misunderstanding, possible difficulties, esthetic expectations, and need for surgical procedures can be evaluated during the initial diagnostic phase.

In the edentulous maxilla, the anterior zone is most demanding from an esthetic, functional, physiognomic, and phonetic point of view. To overcome these complex requirements during oral rehabilitation, various prosthetic reconstructions are proposed for the treatment of the edentulous maxilla (Mericske-Stern et al. 2000; Zitzmann & Marinello 2000a,b,c; Sadowsky 2007; Chronopoulos et al. 2008). In one study, 36% of patients presented bone deficiencies that hindered prosthetically ideal placement of implants (Andersson et al. 1995).

In the present study, it was demonstrated that in the majority of cases, the space between the prosthetic crown and implant platform had to be filled with prosthetic materials. Furthermore, a buccal flange is needed to provide lip and facial support as indicated by measurements such as CID (range between 3.5 and 13.1 mm), MucCov

Table 3. **Medians, mean values, standard deviation (SD), and range of the parameters measured for the six maxillary front teeth**

	Tooth position					
	13	12	11	21	22	23
FLHeight (in mm)						
Median	10.0	10.8	9.6	9.4	10.9	10.1
Mean	10.1	10.7	9.3	9.0	10.8	10.2
SD	2.2	2.2	2.1	2.1	2.2	2.0
Range	4.0–16.0	4.6–17.0	4.6–15.3	3.5–15.8	5.3–17.0	6.2–14.7
MucCov (in mm)						
Median	5.9	6.2	5.7	5.5	5.9	5.0
Mean	5.5	6.1	5.3	5.3	5.7	5.4
SD	2.6	2.9	2.6	2.9	3.4	2.6
Range	−2.7–9.6	−1.9–11.4	−1.8–8.7	−2.2–10.8	−2.8–11.6	−0.2–11.4
CID (in mm)						
Median	7.5	7.6	7.4	6.9	8.2	7.6
Mean	7.2	7.6	7.2	7.0	7.9	7.5
SD	1.6	1.4	2.0	1.4	1.7	1.7
Range	3.7–10.3	3.8–10.7	3.9–12.4	3.9–10.9	4.9–13.1	3.5–12.1
ProsthProfile (in degrees)						
Median	42.6	42.8	36.8	34.3	40.3	42.1
Mean	40.5	41.2	36.0	35.0	40.2	41.4
SD	17.8	21.5	19.8	18.2	15.8	14.6
Range	0.0–80.8	0.0–90	0.0–67.0	0.0–67.1	6.2–67.5	0.0–82.1

Table 4. **Allocation of patients and sites according to the proposed classification**

Classification	Patients *N* (%)	Sites *N* (%)
A – Fixed PD (crown design)	1/43 (2.3%)	3.9
B – Probably fixed PD (hybrid design)	9/43 20.9%	32.4
C – Removable (OD with labial flange)	30/43 (69.8%)	63.8
No implant planning possible	3/43 (7.0%)	–
Total	43 (100%)	100

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(range between −2.8 and 11.6 mm) and FLHeight (range between 3.5 and 17 mm). The broad ranges of all measurements indicated a high individual variability. From a prosthodontic point of view, the restoration of lost tissue can be achieved with either fixed or removable prostheses. Gingival prostheses take several form and various authors have described their uses and methods of construction. Acrylic materials, composites, and pink porcelain are described in the literature for the replacement of lost soft and hard tissues (Tallents 1983; Blair et al. 1996; Botha & Gluckman 1999; Barzilay & Irene 2003). Selection and extent of artificial tissues are related to facial support, emergence profile of the artificial tooth, and the tooth angulation. The use of a full flange extension is mentioned for esthetic advantages (Fortin et al. 2002). However, the application of gingival prostheses may be limited to certain clinical situations where oral hygiene is manageable, function proper and esthetics acceptable. With a removable design, a larger volume of tissue can be replaced and a proper cleaning is still feasible (Barzilay & Irene 2003).

Linear measurements, however, are not sufficient in the decision-making process and measurements of angles (ProstProfile) are important. We considered mucosal coverage (MucCov) and prosthesis buccal profile (ProsthProfile) the most important factors for appropriate treatment planning. In the present study, planning included implants of a minimum 10 mm length. Nevertheless, the comparable survival rates of short rough surfaced implants with standard implants, a tendency of higher failure rates in the maxilla and the lack of randomized clinical trials for fixed implant-supported restorations in the upper jaw, restricted the use of shorter in the analysis (Pommer et al. 2011; Sun et al. 2011; Telleman et al. 2011).

The mean mucosal coverage was about 5.5 mm and only few patients showed negative values, meaning that acrylic flanges extended under or closely beneath the implant platform with no or only minimal need for lip support. A 5 mm extension over the platform was used as the limit for distinction between moderate and advanced cases. The limits for mucosal coverage were put regarding hygienic principles. The design of a normal implant-supported bridge dictates no extension of the materials over the ridge edge. Nevertheless, alternative designs were proposed in the literature providing patients with fixed prosthesis but with flange extensions. These gingival prostheses are predisposing to plaque accumulation more easily and necessitate high ability of dental hygiene. In this study, the limit of 0 mm was the favorable one for correct oral hygiene. A limit value of 5 mm was used for the cases where a fixed prosthesis could be realized under esthetic compromises or in cases where a minimum overlapping of the ridge with artificial gingiva could be designed but with very demanding oral hygiene.

The mean buccal prosthesis profile (ProsthProfile) was around 39 ± 18 degrees with a wide range of values between a minimum of 0 and a maximum of 89.7 degrees. The higher the value, the more perpendicular the position of the crown in relation to the implant platform was. In contrast, lower values represented a crown that was positioned closer to the vertical place. It was proposed that the buccal edge of prosthetic gingiva should not be beyond 45 degrees in relation to the occlusal plane. Its end should also not extend beyond the natural gingival buccal edge when observed laterally (Coachman et al. 2010). In another study, it was proposed that angulation between implants and prosthesis should not exceed 45 degrees. Increased angulation may compromise lip movement when smiling and provide food trap in transition zone (Malo et al. 2008). In these previous publications, the limit of 45 degrees was related to implant angulation and ridge shape. In our study, the same limit was used but in relation to horizontal plane for a fixed implant-supported prosthesis. A lower limit of 30 degrees was proposed to include the cases where a steeper profile could be allowed with some compromises.

In the present study, the buccal profile mean values were found to be mostly lower than the limit of 45 degrees.

We found that only 4% fulfilled the criteria to qualify them for a fixed prosthesis (MucCov $\leq$ 0 mm and ProsthProfile $\geq$ 45 degrees). The position of the crown allowed a physiological transition from implant to the prosthesis (crown) and provided a physiological emergence profile and support. Sixty-four percent of sites were assigned to the group that would benefit from a buccal flange. The remaining 32% included sites with characteristics between a fixed and removable prosthetic solution.

A secondary aim of the study was the allocation of the examined patients.

According to the literature, a minimum number of six implants for a fixed implant-supported reconstruction and four implants for a removable overdenture are needed in the upper jaw providing high survival rates of implants and prosthesis (Lambert et al. 2009; Sagat et al. 2010). In this article, analysis was carried out with the regard of the front region. The analysis consisted two parts. First of all an analysis per site was performed classifying the possible implant's site to one of the groups. This allowed characterization of each site for the possibility of implant insertion and the relationship with the clinical crown position. By accepting the cut-off values, descriptive statistics gave an idea of the tooth loss results. Subsequently, a second analysis was completed giving directions per patient. An even distribution of six implants in the anterior and the posterior region of the maxilla is the most accepted in the literature. For our study, a minimum of two sites in the front area allowing for implant insertion within the limits of each group, was used for the classification per patient. The results showed that only one patient (2.3%) fulfilled the criteria for a fixed design while 9 (21%) could receive a fixed prosthesis with a hybrid design.

Such criteria and measurements may also be helpful when major grafting procedures must be planned in the atrophic maxilla. Bone grafting dimension and quantity could be determined according to these criteria with the help of adequate implant-planning software.

While the presented criteria are helpful for treatment-planning considerations, clinical aspects of individual physiognomy are also important. A low lip line (no gingiva exposed) is advantageous for fixed prostheses with regard to esthetic demands for the upper jaw (Mericske-Stern et al. 2000) as some compromises regarding the emergence profile and teeth lengths may be acceptable. Phonetic problems have been reported more often with fixed prostheses than with overdentures (Jemt 1991; Lundqvist et al. 1992). Impaired phonetics appears to depend also on the palatal design of the prosthesis, which was not considered in the present study.

Technical complications are also described to be associated with compromised implant planning and reconstruction type (Aglietta et al. 2009; Zurdo et al. 2009). It is suggested that favorable 3D implant position and proper choice of the prosthetic design limit the technical complexity of the prosthesis and subsequently reduce technical complications. It was demonstrated that full-arch reconstructions that were planned using implant planning software and CAD/CAM procedures, showed less prosthetic complications than conventionally planned and produced ones (Katsoulis et al. 2011).

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Although measurements for the four points FLHeight, MucCov, CID, and ProsthProfile were carried out by one and the same examiner and reproducibility of the digitizing process was confirmed by means of double determination of all measurements, this may be considered as a weak point in the study design. However, the results for the classification for the population investigated showed a clear tendency. Furthermore, the type and quality of the criteria for decision making were defined before the measurements were performed.

It should be noted that defined decision-making criteria do not replace critical assessment of a set-up under clinical conditions. Implant-planning softwares alone are not able to sufficiently evaluate facial support, lip position and its relationship to the maxillary teeth without a set-up that is tried in and clinically evaluated. However, it is advantageous that clinical observations before implant placement are visualized and verified virtually in combination with simulated optimum 3D implant position. Through this step, treatment outcomes and the choice of prosthetic design become more predictable in the anterior zone of the edentulous maxilla.

Conclusions

The proposed classification and virtual planning procedure simplify the decision-making process regarding type of prosthesis and increase predictability of esthetic and functional treatment outcomes. An idealized prosthetic set-up is an essential tool for the clinical assessment of a patient with an edentulous maxilla and is a requirement for proper computer-based virtual implant planning. It was demonstrated that in the majority of cases, the space between the prosthetic crown and implant platform had to be filled with prosthetic materials. Only few patients were found suitable for fixed implant-supported prostheses with crown design due to moderate or advanced maxillary atrophy.

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