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DEVELOPMENT OF A MODULAR SYSTEM FOR DRILLING AID FOR THE INSTALLATION OF DENTAL IMPLANTS

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ABSTRACT

In oral implantology, proper execution of the holes for the installation of dental implants is directly related to the correct functioning and durability of the system itself. For this reason, the procedure discussed here, which was once performed freehand in all its phases, is now being implemented through aids with more precision. Masks currently in use are created in resin ad hoc; surgical stents are inserted into the holes that will then be used as a guide. These aids are fixed into the jaw by means of micro bone screws in order to prevent movement during surgery. Despite this, we still use the guides as they are, centered properly with the help of drilling jigs. The same technique is also used in partially edentulous cases through smaller jig fixed on teeth near to the implant zone. In this article, we propose a guidance system for milling cutters used in partially edentulous cases involving from one to three adjacent installations. The purpose of the study was to realize a modular model adaptable to most dental implants, as well as efficient, quick, and low cost by pouring the resin into a plaster mold of the teeth, and then drilling the masks into position in the plants at the required angle.

Keywords: dental implants, drilling aid.

INTRODUCTION

The correct execution of the implant is directly related to the functionality of the system and to its duration. The execution of the holes for implant placement must take into account the morphology and characteristics of the bone seat. In fact, inaccurate positioning can affect the stability of the system, compromising osseointegration resulting in failure of the implant. In extreme cases, incorrect installation can also lead to breakage of the implant itself, caused by stress due to masticatory loads, which are not properly absorbed. This loading condition may cause fatigue failure of the structure since the titanium is very sensitive to the fatigue effects [1-4]. In addition, the wrong execution of the implant site and/or the wrong choice of the typology of the implant may be the cause of inflammatory pathologies, with special reference to the alveolar nerve [5-6].

The choice of the system and its relative positioning, with the consequent execution of site, are all up to the dentist. In the planning phase of the surgery, the diagnostic tools currently available make it possible to accurately construct three-dimensional models of the anatomical areas of interest in order to then accurately determine the position, size, and orientation of the implant; DentaScan and CAD CAM techniques are now a reality in this area [7-8].

Over the years, more and more companies have become specialized in the research and development of techniques and methods that facilitate the preparation of the implant site: first, a hole is created in the bone with surgical drill, followed by tapping which is required when a biphasic implant is used to lock the screw, which the prosthesis of the tooth is inserted on. In the case of use of monophasic implant the tapping is not required because a self-tapping screw is used. It is possible to drill the mucous membrane and the gum (flapless) or, after the tissue incision, the gum is opened and only the bone is drilled. The flapless approach, a more recent application, is rapidly gaining popularity, thanks to developments in radiological investigation techniques and 3D reconstruction software that allow a more accurate planning of the intervention [9-11].

The use of the socket is determined by the pre-existing structure and by the class of the bone. If the morphology of the bone or its present state does not allow it, a hole is created from scratch. The procedure varies from case to case in terms of the number and type of cutters used and the depth of penetration of the tip. Both during the approach and during the drilling itself, the path of the cutter follow the appropriate angle, established in the planning phase of the intervention, to ensure that it is extremely straight and as stable as possible. Maxillary or mandibular bone structure might have local weaknesses that, if damaged, can cause the bone failure and to affect the implant site.

At present, in order to assist this operation, instead of using fully manual guides, resin jigs, created from plaster casts personalized for each specific case, are used. The jigs with guide templates are fixed to dental arches by micro screws to ensure stability during drilling. The system is the same as the one used in cases of partial or total edentulism.

It is clear that this methodology, although effective, requires a long time to be realized and the corresponding costs are not negligible, with consequent inconvenience for the patient [12-19].

The purpose of this work is to present a preliminary study of the conceptual design of a modular, easy-to-use and low-cost system, adaptable to different case studies, that eliminates the time of making of the resin jig reducing the costs. The system has been developed to work in all the cases which involve from one to three adjacent implants that are the more frequent situations.

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Preliminary study

In order to achieve a proper design of the system, it was necessary to conduct a preliminary investigation to determine the fields of use of the system in relation to the most common morphology and geometry of the dental arches. It is clear that the borderline cases, which require orthodontic intervention and customized solutions, are not considered. A healthy and adult human mouth has two half (upper and lower) arches, with 4 incisors, 2 canines, 4 premolar and 6 molar. Doubling each of these numbers, because there are two upper and two lower half arcs, a total of 32 teeth is obtained. To define the orientation of the roots the following lines and planes are used (Figure-1, on the left):

- **Occlusal plane (plane-1):** is the lying plane of the line of the teeth.
- **Line of teeth (red line):** is the line that joins the main points of the teeth. This will be abbreviated by LT.
- **Plane normal to LT (plane-2):** the plane in which the lingual-vestibular angle is measured for the lower jaw and the palatal-vestibular angle of the upper arch. The plane contains the axis of the tooth and the normal vector of the line of teeth.
- **Tangent plane to LT (plane-3):** the plane where the distal-mesial angle is measured. It is the plane that contains the axis of the tooth and the tangent vector of the line of teeth.

The angle between the projection of the normal to the occlusal plane on the plane-2, towards inside the oral cavity is the lingual (palatal) angle. The angle between the projection of the normal to the occlusal plane on the plane-2 and the vertical direction, towards outside the oral cavity, is the vestibular angle (see Figure-1, in the middle). The angle between the projection of the normal to the occlusal plane on the plane-3 and the vertical direction, towards to the last molar, is the mesial angle. The angle between the projection of the normal to the occlusal plane on the plane 3 and the vertical direction, towards the first incisor of the considered half arch, is the mesial angle (see Figure-1, on the right).

Each type of tooth (incisor, canine, premolar, and molar) has its root orientation that is similar for all the people. If the occlusion is correct and the alveolus of the root is healthy, the implant will be placed following the original inclination of the root; otherwise, the system will be inserted where the bone allows it, in order to correct the defects and ensure a perfect occlusion. Statistically, the most common values of the angles of the roots are included between two known values reported in Table-1 [19-29].

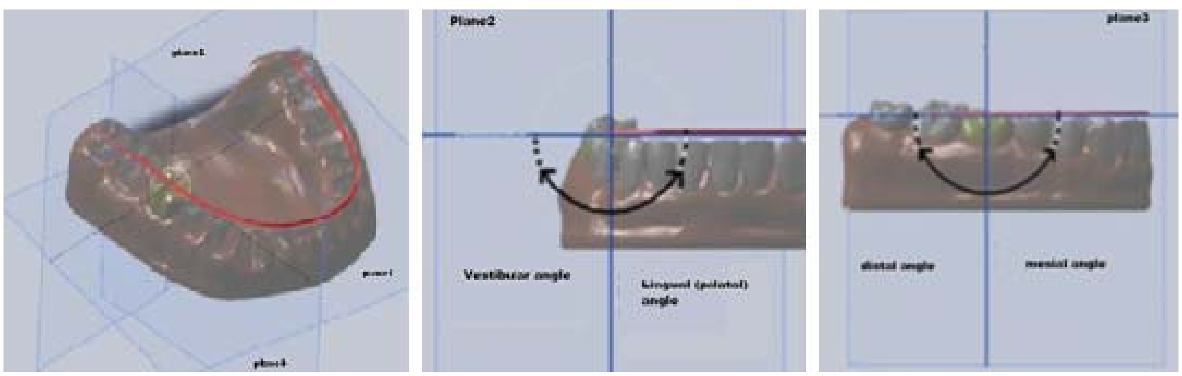

Figure-1. Teeth reference. Plane of mastication (1); plane normal to the LT (2); Plane tangent to LT (3). Characteristic angles are shown.

Table-1. Values of the angles of the roots.

TOOTH	MESIAL ANGLE ? *M*	DISTAL ANGLE ? *D*	LINGUAL ANGLE ? *L*	VESTIBULAR ANGLE ? *V*
Upper right central incisor	0°	2° - 3°	15° - 25°	0°
Right upper canine	0°	10° - 15°	10° - 15°	0°
1st upper premolar dx	0°	2° - 5°	2° - 10°	0°
2nd upper premolar dx	0°	2°- 8°	2° - 10°	0°
Top right 2nd molar	0°	0° - 5°	5° - 20°	0°
Lower right lateral incisor	0°	3° - 6°	0° - 5°	0°
Right lower canine	0°	2° - 10°	0° - 10°	0°
1st right lower premolar	0°	5° - 10°	5° - 10°	0° - 2°
2nd premolar right lower	0°	7° - 12°	0° - 5°	0° - 2°
1st right lower molar	0°	10° - 20°	0° - 5°	0° - 15°

All teeth have mesial angle zero- i.e., all the roots, in the plane normal to the LT, are always vertical and oriented towards the back of the oral cavity. In addition, vestibular angles to the upper jaw are not present, while they are different from zero for the lower arch. Each tooth, however, has mesial-distal and vestibular-lingual angle. It follows that the roots do not always lie on a single plane, but are spatially oriented. It has to be considered during the development of the system guide for drilling. The possibility of orientation of the system guide must to allow following every possible angle of the root. The absolute angle of tilting (αT) is given by the formula:

$$\tan(\alpha T) = \sqrt{\tan^2(\alpha M) + \tan^2(\alpha L)} \tag{1}$$

where αM is the mesial angle and αT is the lingual angle.

Other considerations relate to the spacing of the teeth, which are directly related to the size of the teeth. As a first approximation, the tooth, seen from the occlusal plane, is similar to a circle: using this assumption, the design of the jig would be more convenient but less accurate. In fact, the tooth has an irregular shape, but has two characteristic parameters: the vestibular-lingual width and the mesial-distal length. This last will be considered in the design because the space between the teeth is measured on the plane tangent to the LT Table-2 shows the mesial-distal length of the teeth:

Table-2. Mesial-distal length for different types of teeth.

Teeth	MIN (mm)	MAX (mm)
incisors	4	10
canines	5	9
premolars	6	9
molars	9	13

By using geometrical considerations, it is possible to evaluate all the different cases that may occur. This computation influences the specification of the proposed assisted device. For example, the calculation of the center distance (the distance between the axes of the teeth projected on the occlusal plane) for a single implant of the second premolar may be made by the following relations, where the adjacent teeth are the first molar and the first premolar:

$$l_{min} = \frac{L_{prem,min}}{2} + L_{prem,min} + \frac{L_{mol,min}}{2} = 13.5 \text{ mm} \tag{2}$$

$$l_{max} = \frac{L_{prem,max}}{2} + L_{prem,max} + \frac{L_{mol,max}}{2} = 20.0 \text{ mm} \tag{3}$$

where l_{min} and l_{max} are the minimum and maximum distances, respectively and $L_{i\,min}$ and $L_{i\,max}$ are the minimum and maximum length characteristics of the i-th tooth.

Table-3 shows the calculated values in the various cases of interest. All the values listed in Table-3 are calculated by similar analogous relationships.

Table-3. Values of the center distances for the single, double and triple implants.

SINGLE IMPLANT	l_{min} (mm)	l_{max} (mm)
2nd molar	18	26
1st molar	16.5	24
2nd premolar	13.5	20
1st premolar	11.5	18
canine	10	18.5
DOUBLE PLANT	l_{min} (mm)	l_{max} (mm)
1st and 2nd molar	25.5	37
1st molar - 2nd premolar	22.5	33
2nd and 1st premolar	19	29
1st premolar - canine	16	27.5
TRIPLE PLANT	l_{min} (mm)	l_{max} (mm)
2nd, 1 mol. - 2nd prem.	31.5	46
1 mol. - 2nd, 1st prem.	28	42
2nd, 1st prem. - canine	23.5	38.5

The developed jig for the drilling guide takes in to account the values of the previous Tables to calculate the distances between the axes of the teeth and to dimension the fixtures of the system. The connection is made on the healthy teeth near the zone of the implant. In addition, the system has to be a little bit flexible to follow the curvature of the dental arch.

Regarding the inclination angle for the insertion of the implants, there normally is a particular inclination for each family of tooth; angled abutments are used to align the prosthetic crown to proper occlusion. The angles that are produced with standard abutments, are the absolute angles of implantation: 0°, 5°, 7.5°, 10°, 15°, 18°, 20° , depending on the tooth that it replaces. These values will then be permitted by the guides for the cutters of the developed system. It is also necessary to take into account the diameter of the cutter; the values most commonly used in commercial products are:

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- 1.8 mm drill used in mini-implants;
- 2 mm pilot drill and lanceolate;
- 2.2, 2.75, 3, 3.5, 4, 4.35, 5, 5.50, 6 mm drill.

The last three values are used in special cases, therefore they will not be considered during design. Last, but nonetheless important to take into account in the design, is the distribution of stresses on plants: an incorrect positioning may cause the values of the stresses up to failure or breakage of the implant. Another important factor that changes stress distribution is the scheme of placement of the implants. In the case of 3 implants the configuration does not follow a line but a tripod (see Figure-2). The tripod scheme counteracts bending movements, decreasing the wearing and stabilizing the system. Furthermore the grater area, compared to linear configuration, decreases the stress on the implants and the bone. For these reasons, in the case of 3 implants, the tripod configuration is adopted [30-33]

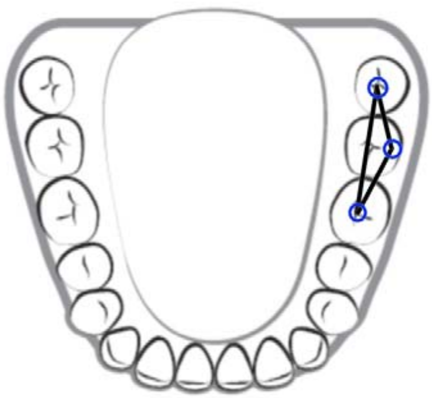

Figure-2. Cantilever configuration.

System design [34-36]

In addition to the geometric considerations described in the previous paragraph, it should be noted that the system has been designed in order to adapt to more frequently seen cases, namely:

- Single implant
- Double contiguous implants
- Triple contiguous implants
- Single post-extraction implant with immediate loading

In more complex cases or in the case of edentulous vice versa, ad hoc solutions are required.

The first investigated problem is the variability of the diameters of the drills. A device similar to a bush, called *sleeve*, where the drill head can slide, was developed.

The sleeve's inner diameter will vary, depending on the cutter to which it is coupled, and the outer diameter will be equal to that of the universal guide. So the design was oriented to develop a composite system in which sterilizable and reusable parts (guides, sleeves, milling) can be purchased as a one-off item, with sterile and disposable parts (masks) included, which due to their low production cost, can be manufactured in large quantities and provided to the dentist regularly. In addition, the pre-operative system configuration can be easily done on the plaster cast of the dentation of the patient of the patient. Once the system is installed in the oral cavity, it will be removed only at the end of the operation; it does not require in-progress settings. Various other solutions were considered but for brevity are not shown here. The final model chosen is depicted in Figure-3, which shows configurations for a one-implant system (above, on the left), a two-implant system (above, on the right) and a three-implant system (below), with the drills inserted and the teeth schematized in simplified form.

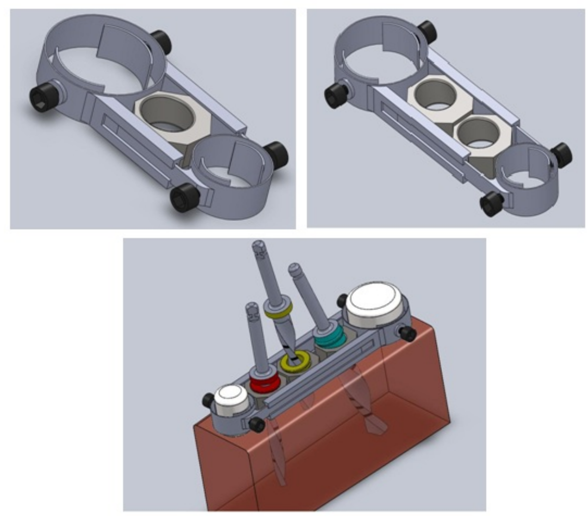

Figure-3. Implementation of the proposed system for single (above, on the left), double (above, on the right) and triple implants (below).

Figure-4. Guides (up) and sleeves (down).

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The guides of the developed system (Figure-3) feature octagonal outer surface adapted to prevent movement once inserted into the mask and internal cylindrical axis tilted in the values 0°, 5°, 7.5°, 10°, 15°, 18°, 20°, where they will enter the sleeves (Figure-4). To accommodate the cutters on the market, the sleeves are produced in the values of 1.8, 2, 2.2, 2.75, 3, 3.5, 4, 4.35 mm.

The mask is composed of two parts (Figure-5) which slide in relation to one another, thanks to a rail that allows it to adapt to different situations.

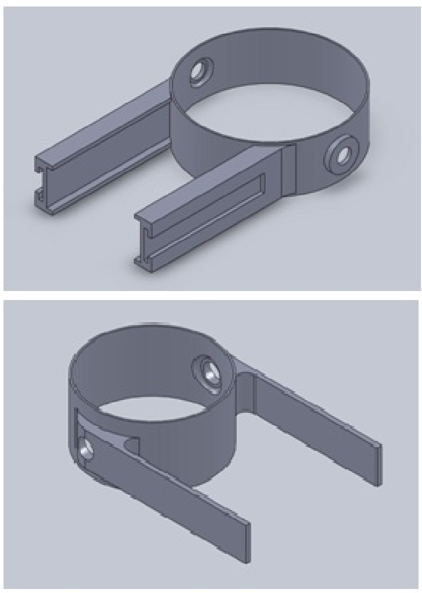

Figure-5. Mask of the proposed system (with female rails, up and with male rail, down).

The tooth-fastening system, shown in Figure-6, ensures adaptability to different cases through a clamping system that is adjustable by screws.

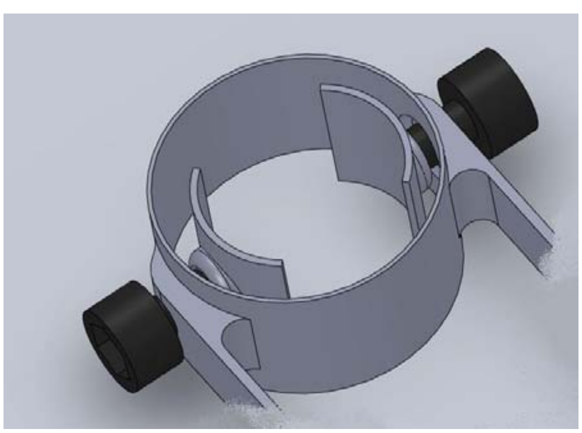

Figure-6. Clamping system.

After the planning of the surgery, all the pre-assembling phase is made on the plaster cast, where different configurations are tested. The part of the system with the female guide-track is positioned on the distal tooth, without fixing the blocking system. The chosen sleeves are inserted on the female rail following the correct order. As a second step, the part of the system with the male rail is inserted and mounted on the mesial tooth. Then, all the positions are adjusted and the system is blocked with a shrink-fit between the female and male rails, to prevent sliding (Figure-7). This operation can be made by use of a common dental forceps.

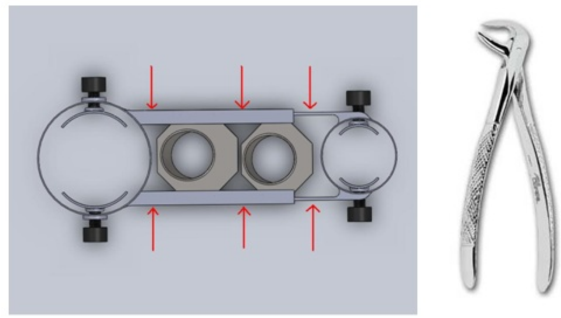

Figure-7. Shrink-fit of the rails (on the left) obtained by using dental forceps.

After the adjustment, the system can be positioned in the in the oral cavity of the patient and fixed on the teeth tightening the micro-screws by a hexagonal wrench.

At this point, the drilling phase can begin. The guide system has been developed leaving the gum exposed, which facilitates blood removal. Moreover, the spaces between the guides allow for good penetration of the liquid salt at low temperature that should lubricate the area. This is another advantage with respect to the standard resin masks that do not allow the lubrication.

After the drilling phase the system can be removed easily, unloosing the micro-screws and the implants can be installed.

The system thus configured makes it possible to avoid the construction of the drilling jig in resin, and reduces execution time and costs. In addition, the pre-setting can be done on the plaster cast, which also reduces the patient's discomfort. With a single set of standard parts along with reusable and disposable equipment, the most common and most frequent dental implant cases can be treated.

It should be obvious that this method cannot be used in cases of extensive or total edentulism, or in situations that are beyond the standard cases. In such cases, however, the complexity of the clinical situation justifies the need for customized solutions.

CONCLUSIONS

A preliminary study was conducted for the development of a modular system for facilitating the drilling operations required for the installation of dental implants. The proposed apparatus-usable in standard cases of partial edentulous, involving up to three installations-makes it possible to avoid the building of the resin mask guide, thus reducing the total time of the surgical procedure.

Many of the components constituting the system are reusable.

The possibility of performing a pre-setting of the mold decreases the number of operations to perform within the oral cavity with evident benefits for the patient.

The design, albeit in a preliminary phase, was conducted taking into account the observations of dentists, who confirmed the feasibility and functionality, in theory, of the proposed methodology.

Obviously, only a subsequent clinical trial will confirm the full validity of the developed system.

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