PRE-OPERATIVE PLANNING OF DENTAL IMPLANT THERAPY: OPTIMUM IMPLANT AXIS ALLOCATION

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ABSTRACT
Preoperative planning of the therapy with oral endosseous implants is a complicated procedure with many parameters to be taken into account. In this work, a method based on processing of CT images is presented, that contributes to the automatic and optimum allocation (position and orientation) of an implant’s axis. Respective optimization criteria are established in conjunction with the geometrical structure and quality of the hosting bone. The aesthetical result of the prosthesis is also considered, requiring from the patient to wear a scan template. An application example of the developed Imfix algorithm is discussed.

KEY WORDS
Preoperative Planning, Dental Implant, Axis Allocation

1. Introduction

Implant dentistry has witnessed a significant expansion in applications, technology and methodologies. In the last years several software tools appeared, with the aim to support pre-operative planning of dental implant treatment and thus to increase the level of confidence during this medical procedure [1-5, 7].

The use of computerized tomography (CT) images and their 3D reconstruction improves significantly the available planning information [8]. Through this enhanced visualization, which includes 2D views of the oral anatomy (axial, panoramic, cross-sectional images) and, as well as, the 3D representation of it, most of the planning procedure is transferred on the computer screen. Several planning alternatives can then be tested and discussed until the most suitable one is chosen and put into practice. Most of unexpected intra-operative hazards are thus minimized.

Whereas this new methodology of dental implant treatment planning can lead to more accurate diagnosis and higher rates of successful design of the therapy, the result is still considerably dependent on the doctor’s competence. Current planning software still expects most of the input from the doctor. Neither automated nor optimized procedures have been yet developed, in order to direct him to a more controlled design.

The development of a novel approach that has as objective to reduce the contribution of the subjective factor in determining the allocation of a dental implant’s axis is presented in this paper.

The method exploits the patient’s CT data and introduces medical, dimensional and geometrical criteria in order to optimize the dental implant location and, as well as, orientation. This is implemented by applying image-processing techniques, such as thresholding, region-based processing, and automated morphological calculations.

At its present status the algorithm “Imfix” that implements the method, deals with the case of mandible. A four single tooth case study is presented and discussed.

2. Background

Computer aided pre-operative planning for oral implant treatment has been evolved as a useful and convenient tool towards a successful therapy. Programs such as DentaScan and later on SimPlant, coDiagnostiX, ImPlacer and Oralim, have expanded the diagnostic and treatment planning capabilities compared to the traditional methods [1-5].

Common characteristic of the above is the graphical environment, where the image data of the patient can be viewed in several forms. In two dimensions, the initial axial images can be reformatted to be displayed as a panoramic image or as cross sectional images along a user defined NURBS curve. The 2D data can also be reconstructed to a triangulated 3D model. Within this graphical environment virtual 3D implants can be inserted in the anatomy and studied. Implant’s position is viewed simultaneously in 2D and 3D and its position can change interactively by the user and be displayed in real-time.

Furthermore, a capability of localizing vital structures, such as the alveolar nerve channel, is offered through 3D graphics [9]. A 3D NURBS curve is used to
fit in the corresponding channel and route a solid pipe which depicts the structure to be cautioned. This 3D object is visible in all 2D views making planning more efficient. There are finally additional tools which aid reaching to a plan decision, such as precise measurements of lengths and angles on the anatomy and also information on the bone density.

Digital information extracted from CT images can be further manipulated in order that computer assisted planning becomes more intelligent and automated. In [10] an automated method is introduced to position a stem implant in a host femur anatomy. An equally accurate positioning of the prosthetic component between the automated and the manual way by an expert surgeon is reported. In [11] the need of cross sectional images, that fully contain the axis of the implant to be installed so that accurate measurements are taken, is stressed. An automated method of re-orienteering CT images is presented.

To this date an automated process for the optimum allocation of a dental implant axis, that makes use of appropriate biomechanical criteria, has not been presented.

3. Design Considerations

Pre-operative planning of dental implant treatment is a time consuming and complicated procedure, the success rate of which directly affects the final outcome of the treatment itself. Main factors that need to be studied during design involve anatomic geometry as well as quality of the bone mass. As osseous structure and morphology varies from patient to patient, the information contained in the CT images is critical for the allocation of a dental implant inside the jaw. Furthermore, the existence of a prosthetic superstructure must be taken also into account for a satisfactory aesthetic and functional result [9]. For this reason it is proposed that the patient should wear a radio-opaque template of the provisional tooth setup during scanning. This template, or else the scan prosthesis, is a duplicate of the diagnostic teeth set-up and offers useful information for the subsequent planning procedure.

As far as the bone anatomy is concerned, the absence of periodontal ligament from bone-implant interface causes a more direct transfer of occlusal loading to the facial skeleton [13]. The absorbing property of the ligament has to be replaced directly by bone that has to withstand those loadings. Consequently, two factors that can assist towards implant allocation and orientation are the quantity and the quality of the recipient bone [14], [15].

The existence of a prosthetic superstructure, which participates in load transmission, has also to be considered. Occlusal surface and underlying implants should be in the same vertical axis, so that torquing forces are eliminated. The geometry of the provisional crown, as it is radiographically depicted, adds therefore another parameter in design.

At the current stage of this research, the following three criteria have been established for an optimum allocation and orientation of a dental implant:
I. Uniform geometric distribution of the surrounding the implant’s axis bone volume.
II. Uniform density distribution of the surrounding the implant’s axis bone volume.
III. Uniform geometric distribution of the provisional superstructure volume around the implant’s axis.

According to the first (I) and second (II) criteria, the axis inclination of the implant is positioned in such a way that a uniform distribution of the surrounding bone volume and density is achieved. It is assumed that having the most possible bone mass around an implant, then a more stable support against multi-directional long term loading is assured. A similar technique, called “triangle of bone” has been proposed in [13] for the determination of the central orientation of the implant axis. It is here to be noticed that a more in depth approach would favor the inclination of the implant axis towards a direction where a greater mass of supportive bone would exist with regard to the valid or common occlusal force vectors for each type of tooth. In this case one more biomechanical criterion has to be added, a task that is currently under investigation within the frame of this research.

Finally the esthetic aspects of treatment in

![General flow diagram of the Imfix Algorithm](image-url)

**Fig. 1** General flow diagram of the Imfix Algorithm
coordination with the projected morphological and functional rehabilitation are considered through the third criterion (III). A similar approach as that in the first two criteria is applied: Implant axis has to extend centrally through the volume of the prosthetic crown. As a consequence, cantilevering torquing forces that are thought to be particularly hazardous to osseointegrated interface are moderated.

4. Method General Concept and Current Status

The present method is based on the processing of digital images derived from CT scans of the patient’s mandible or maxilla. It is developed within the MATLAB environment by using in particular its Image Processing Toolbox, [6].

CT digital data involve a series of images which are represented by 2-dimensional arrays of pixels. The last ones are called voxels, which are 3-dimensional pixels, since each slice of the scanner has a given thickness. Each voxel contains information about the 3-dimensional location of an anatomical element and its attenuation coefficient, which is a measure of its average density. Image processing technology manipulates this kind of data to a specific cause.

What is primarily investigated is what part of the anatomical morphology will be included during the implant allocation optimization. The critical bone volume which is going to envelop and support the implant is designated by the user, who draws one or two quadrilateral frames on selected images. In this way a hexahedron is formed, that segments the region of interest. If a scan-prosthesis is included in data, the hexahedron will segment the corresponding prosthetic structure as well.

According to the criteria of the previous section, the method aims to determine those points which best approximate the line of the implant-axis to be adopted. The objective is that in every image a point is qualified. The qualified points from every slice are then used, through linear regression, for the approximation of the implant axis line.

In accordance with the first (I) criterion, as qualifying point of each two-dimensional segmented slice of this bone volume is taken its centroid. As foreseen by the second (II) criterion, the centroid coordinates calculation algorithm takes into account the pixel densities as represented by their grey values.

Furthermore the contribution of the esthetic criterion (III) is taken into consideration by incorporating the centroids of those segmented slices which contain the cusp of the prosthetic restoration. It is to be pointed out here the subtle biomechanical logic of this (III) criterion: not only the mandible or the maxilla but also the provisional tooth will be accepting the occlusal loading. The morphology and geometry of this artificial tooth possesses a natural shape, fulfilling functional demands. Thus the centroid of the closed contours in every axial image of the tooth suggests valid points for the implant axis.

An overview of the current status of Imfix is shown in Fig. 1. It produces two points in the 3D space, which determine the implant’s axis. On the basis of this axis further analysis can then follow.

Initially an operation of thresholding is applied to every image according to a critical grey-value that the user has specified. This value can be achieved through itinerary trials in a way that the osseous anatomy is well separated from its background.

As soon as the anatomic object of interest is outlined, a more specific selection of a region takes place. The user is called to decide on the segment of the jaw, where the insertion of an implant is going to be planned. The selection is carried out by sketching a polyline around a part of the jaw or around the crown of the provisional tooth, as it is depicted in a suitably chosen axial image. The last option facilitates a more accurate choice, since the cross section of the cusp features better and easier the respective bone supporting area. The three dimensional region of interest (ROI) is then constructed by using the same frame to segment all remaining images that participate into planning. Alternatively, when a more versatile ROI designation is needed a second frame can be drawn on another axial image. These are e.g. the cases when sensitive structures lie nearby, or of maxilla where the front region has usually an intense proclivity.

The way the user draws the polyline frame can affect the outcome of the analysis. It is important to specify how this frame should be drawn. The following guidelines have been adopted:

- Four lines are sufficient to design the closed polyline (Fig. 2).
- Two of those lines should intersect vertically the arch of the jaw and be tangent to the contour of the artificial tooth.
- The other two lines are drawn outside of the osseous area in such a position that they lie outside of the osseous area in every input image.

The centroid of each slice is obtained on the basis of the coordinates of the non-black pixels and their grey values. A brighter pixel is treated as a “heavier” one. The centroid coordinates generate then the implant 3D line axis using the least squares regression method.

**Imfix** results are graphically displayed in the following forms:

a) In 2D axial view depicting the trace of the axis.
b) In 2D “axis sectional” view that is not vertical to the CT images plane, but inclined to contain the full implant axis line. It has been proved that this kind of view allows more accurate medical measurements [11], [12].
c) A vivid 3D display of the respective anatomy with the suggested implant axis that is realized using the **Mimics** software [2].

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5. **Case Study and Discussion**

The digital data of the patient with the codename “Simon” have been retrieved from the Tutorial Files of **Mimics** Software. The set of axial images concerns the

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patient’s mandible. A scan-prosthesis is also present, which shows the provisional teeth setup. The artificial cusps and the entire tooth contour guide the ROI assignment, and their volume contributes to the calculation of each implant axis.

The mandible misses totally four teeth, so maximally each one could be replaced by an implant supported restoration. In this application, Imfix is used for every single tooth site separately, as free splinted completed crowns be the final restoration. The four instances concern the mandibular left first premolar (4L), second premolar (5L), first molar (6L), as well as the mandibular right first molar at the space of premolar (5R) (Fig. 3).

For 6L there is an approximately available height of 8mm, between -21.50 and -29.50, for an implant to be inserted (Fig. 4a). The second set of images, which their axial coordinates range from -15.50 to -7.50, contains the provisional tooth setup. Both sets comprise the input images needed for the axis allocation analysis. They were segmented by the quadrilateral polyline shown in Fig. 4b and the produced by Imfix implant axis is shown in the axis sectional view of Fig. 4c. A Mimics 3D rendered view is given in Fig. 4d. The other cases were treated in a similar way. The input images, the segmentation frame and the resulted implant axis can be seen for 5L in Fig. 5, for 4L in Fig. 6 and for 5R in Fig. 7.

As the obtained results demonstrate, each suggested implant axis is optimally enveloped by bone as well as by the provisional prosthesis. This allocation can therefore be considered that constitutes an optimal support against occlusal loadings. The maximized mass around the axis in the host bone gives the doctor the opportunity to try for maximum size range of implant diameters. Furthermore, the optimized space around the axis in the prosthesis volume offers more comfort for any restoration work.

6. Conclusion

The aim of operational planning in oral and maxillofacial surgery is the optimization of the surgical result with regard to function and aesthetic aspects. The presented method has been designed and developed towards this direction, dealing with the allocation of a dental implant axis and its optimization under certain biomechanical criteria. The pilot application of the Imfix algorithm encourages for further work and testing to be carried out. Parameters such as the implant basic dimensions, the properties of bone around the implant and the biomechanical behavior of the system are issues for further research. Planning standardization with respect to treatment protocol and design methodology should be also included.

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