Chapter 7
Method to Support Dental Implant Process Based on Image Processing

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7.1 Introduction

The continuous evolution of the processing capacity of computerised systems combined with image processing techniques, artificial intelligence and reengineering has enabled the conception of expert systems capable of developing activities in an automatic manner, helping people in complex tasks or providing support for decision making.

In parallel with this evolution, computed tomography, created in the 1970s by Hounsfield (1973), revolutionised diagnosis by images, allowing the use of image processing algorithms in data extraction, three-dimensional reconstruction and in intelligent fault reconstruction systems (Canciglieri Jr. et al. 2010). However, although some areas already use these systems, others, such as implant dentistry, rely on the experience of the dental surgeon to define the implant and the prosthesis to be used.

These definitions occur through visual analysis of computerized tomography or magnetic resonance imaging, where the dental surgeon identifies the dental fault and analyses the region to be implanted, checking bone volume, nerve location, bone and tooth boundaries.

Based on this context, this chapter presents the study of the conceptual proposal of an expert system of design oriented to the process of dental implantation, whose objective is to seek from the concepts and techniques of image processing and dental implantation, to formulate a conceptual model that provides support for decision making through an expert system. This model has inference mechanisms that are

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able to capture information contained in a representation, convert them, translate them and/or share them with other representations, offering subsidies to the dentist in choosing the most appropriate dental implant.

As main contributions of this research we can highlight: (i) improvement of the dental implant process based on analysis of precise information of the patient's dental arch extracted from CT images; (ii) reduction of the surgical procedure time, due to a previous planning of the dental implant process as well as the reduction in the dental implant absorption time due to trauma reductions; (iii) reduction of the dental implant rejection risks.

7.2 Research Methodology

This research is considered of applied nature, because according to Lacerda et al. (2013) seeks to understand, explain and produce knowledge for practical application, directed to the solution of specific problems, through theories already formulated. According to Collis and Hussey (2005), the applied research aims to find ways of applying the process to solve a problem, characterizing as exploratory, because it aims to provide insight into the subject and then propose a conceptual method. Regarding the approach, it is qualitative, because it seeks a deep understanding of a specific phenomenon through de-descriptions, comparisons and exploratory interpretations, in order to provide greater familiarity with the problem, according to Berto and Nakano (2000), researches of qualitative nature seek to unite the theories of facts, whether through the description and interpretation of conditions or events, generating knowledge through the relationships between the context and the actions of the process, generating particularized results based on phenomenological analysis of the researcher. This approach, according to Miguel et al. (2018), houses a series of interpretation techniques that seek to describe, decode, translate any other term related to the understanding and not to the frequency of occurrence of the variables of a given phenomenon.

The scientific objectives of this research are exploratory, as they propose a greater knowledge of the phenomenon whose definition or problematic are not yet completely explicit, as new variables need to be assessed in order to understand the impact they cause in the solution of the problem. The technical procedures adopted in this research are bibliographic and experimental. Bibliographical, because based on the bibliographical revision the knowledge to develop the conceptual model of the expert system of design oriented to the dental implant process was built. It is experimental, because initially it is necessary to determine the object of study and de-define the variables that influence the process, being possible, in this way, to control the object under study, differing from a case study, according to Souza et al. (2013), aims at the materialization of a product or service and/or the feasibility study of this, as in the case of the development of a decision support method.

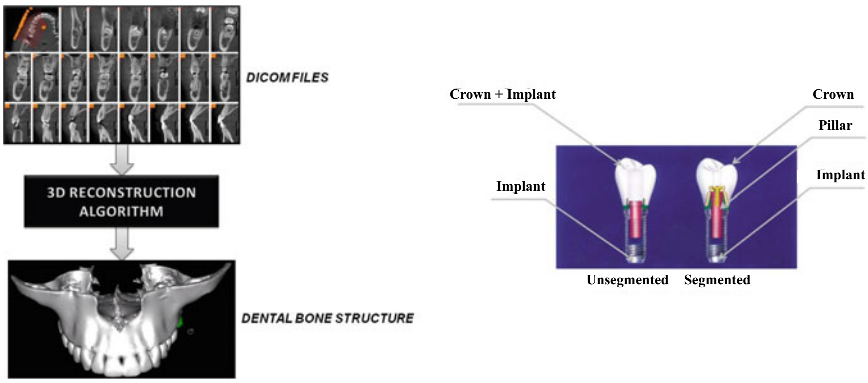
7.3 Background Technologies

The evolution of computerized systems has made it possible to develop increasingly complex algorithms that perform processing almost instantly, being used increasingly in biological areas and helping the planning of diagnoses and treatments (Grauer et al. 2009). These diagnoses are often obtained by means of CT and MRI images in DICOM standard, allowing the extraction of characteristics or patient information.

Computed tomography is a method of image acquisition and reconstruction of a cross section based on attenuation measurements, as compared to conventional radiographs. These images are free of tissue overlapping, allowing the generation of a better-defined contrast, due to the elimination of scattering (Silva 2018).

The DICOM standard allows the evolution of image processing algorithms, since the information that is obtained, regardless of the manufacturer, are equal, allowing efforts to be focused on the development of systems in order to support doctors, dentists and nurses in their activities. Moreover DICOM image files, as shown in Fig. 7.1 detail "A", can be converted into different formats, allowing them to be viewed on computers without dedicated applications and with the aim of compressing the size of the image file, allowing them to be sent over the network to remote computers (Graham et al. 2005). However, depending on the choice of format there may be considerable loss of important information for the analysis of this image (Wiggins et al. 2001).

In the case of implant dentistry, a branch of dentistry aimed at treating edentulous patients with dental implant rehabilitation, there has been an increase in the use of such equipment, especially in the area of 3D image reconstruction by means of computed tomography, providing a better visualization of the patient's bone structure to the dental surgeon (Greboge, Canciglieri and Rudek 2010). This approach overcame some of the limitations found in conventional dental implant treatment



(A) 3D virtual reconstruction (B) Dental Implant

Fig. 7.1 Dental reconstruction and implant framework planning, especially in the pre-implantation stages, where it was based on 2D data obtained by MRI. Moreover, in this multi-view graphic environment, it provides image reconstruction, increasing the interactivity of the dental surgeon with surgical planning (Grauer et al. 2005).

An important point to be considered is also the advantage of using fixed prostheses (screwed), because according to Misch (2006), it is the longevity that these prostheses have when compared with partially fixed prostheses (screwed and cemented). The use of screw-retained prostheses reduces the risk of caries, improves hygiene, reduces the risk of sensitivity and contact with the root of existing teeth, improves the aesthetics of the prosthetic pillars, the hygiene of the bone in the edentulous space, reduces the risk of tooth loss of the prosthesis, and also the psychological aspect. The disadvantages are the high cost, long treatment time and the possibility of implant insertion failure due to inadequate planning and execution. Bottino et al. (2006) report as an advantage the non-occurrence of the re-absorption process of the bone structures that surround the missing dental element, as there is no absorption of the soft bone present in this region.

The implanted fixed prosthesis can be divided into segmented and non-segmented prosthesis, as illustrated in Fig. 7.1 detail “B”. The segmented prosthesis consists of three distinct parts: implant, abutment and crown, whereas the non-segmented prosthesis consists of only two parts: implant and crown (built from an abutment connected to the prosthesis) facilitating the aesthetic result (Ochiai et al. 2003; Lewis et al. 1995; Breeding et al. 1995).

The use of computed tomography in the process of dental implantation has made the procedure increasingly safer, as is the case in other areas that already use these images in three-dimensional (3D) modeling, such as cranial reconstruction (Greboge et al. 2010), where it is possible to geometrically reconstruct the bone and virtually correct any flaws that may exist in the bone. These virtual reality technologies have been widely disseminated, improving the interpretation of patients’ tomographic images in order to improve performance in the planned treatment and reduce recovery time.

7.4 Design for Dental Implant—*DFDImplant*

In dental implant processes, the dental surgeon specialist must determine which implant should best adapt to the patient, always taking into consideration the patient’s dental structure through images obtained by computerized tomography. However, analysis based only on images is not deterministic and data such as bone density, area, bone volume, geometry of nerves, among other variables, are important to define the most suitable implant should be used. These variables are not found directly on the images, leaving it up to the experience of the dentist (oral and facial surgeon) to define the best implant, and in many cases, this ends up occurring during the surgical procedure without adequate planning. The inaccurate and reduced information makes the definition of the dental implant difficult and imprecise, and may cause its premature failure, bone loss, implant rejection and infections, compromising the treatment of partial and/or total edentulousness (Pye et al. 2009; Li et al. 2010).

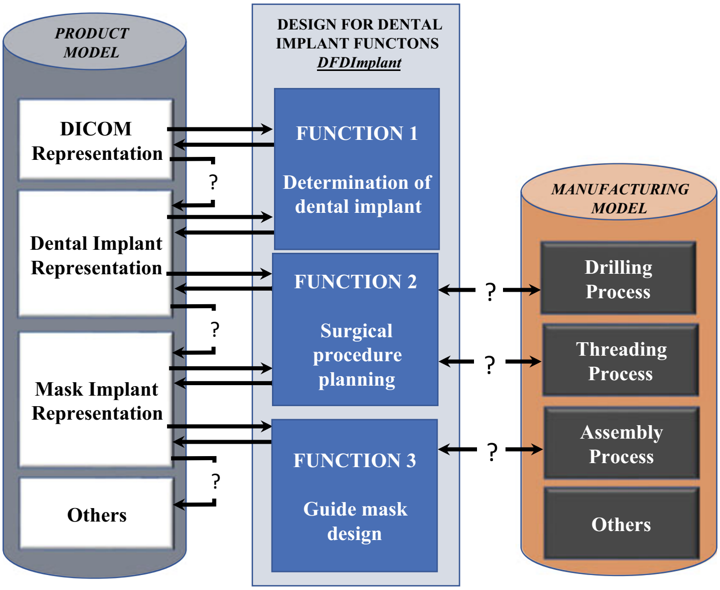
The existing computer systems only provide the dentist with the process of three-dimensional reconstruction of the dental arch (Galanis et al. 2006), but these systems do not offer the subsidies or interactivity that the dentists need in their decision-making to determine the implant, as occurs in computer-aided diagnosis systems. These systems are important tools used and accepted in the medical field, as they provide support to the specialist based on knowledge already tested by specialists' dentists in their diagnoses. However, in the literature review (Tinfer et al. 2020), the use of this type of system in the dental implant planning process was not identified. However, it was found that it is possible to design a system of this level meeting this need, based on the processing of images obtained by computerized tomography. This system must be capable of analysing these images and selecting, based on the characteristics obtained, the set of implants and abutments which best suit the patient, supporting and corroborating the decision of the specialist dentist, contributing to a more suitable surgical planning.

The selection of the dental implant is a process of simultaneous and independent analysis of aspects such as bone structure, nerve positioning, geometry of the mouth and dental arch. Thus, the Design for Dental Implant Systems—***DFDImplant*** must provide support to multiple processes by performing a simultaneous and automatic analysis of the images searching for features that fulfill these issues, providing enough information to subsidize the selection of the set of implants that best fit each patient. Figure 7.2 illustrates the proposed conceptual framework of the ***Design for Dental Implant Systems—DFDImplant*** that is based on the concepts of product and manufacturing models. The question marks "?" (Fig. 7.2a) represent the existing interactions between the different representations within the Product Model and the existing interactions between the *DFDImplant* functions and the existing information in the Manufacturing Model.

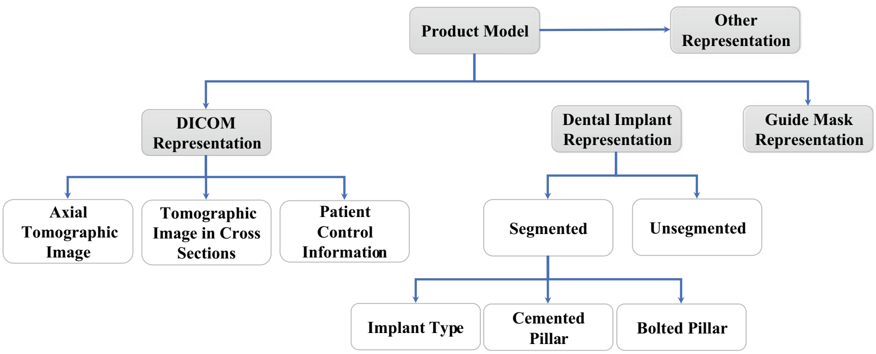
The ***Product Model*** must be responsible for storing the requirements and information specifications needed to support the functions that compose DFDImplant. Each of these representations contains the information related to the product and to the dental implant procedures or techniques, such as the DICOM representation, which contains the tomographic files and patient information. Figure 7.2b illustrates the generic hierarchical structure of the Product Model consisting of DICOM, Dental Implant (Fig. 7.2c) and Guide Mask Representations respectively. Figure 7.2d illustrates a set of tomographic slices highlighting the region of interest where one or more of the patient's teeth are missing.

The ***Manufacturing Model*** should be responsible for storing the information regarding the manufacturing processes required during the stages of the surgical process. The Manufacturing Model contains the manufacturing technologies and knowledge that may help the dental surgeon during the procedure of implant insertion in the patient, such as drills, tools for tapping, torque wrenches, among others. However, the issues involved between the existing representations in this model will not be addressed in the research reported in this chapter.

The ***Design for Dental Implant Functions*** (***DFDImplant***) must be responsible for the definition of the inference mechanisms between one representation and another for the *conversion*, *translation* and *sharing* of information. These functions determine the selection of the most suitable dental implants for each case, taking into account the information from DICOM representations, Dental Implant and Mask representations in the product model, associating it with the most suitable manufacturing process contained in the representations in the manufacturing model (manufacturing

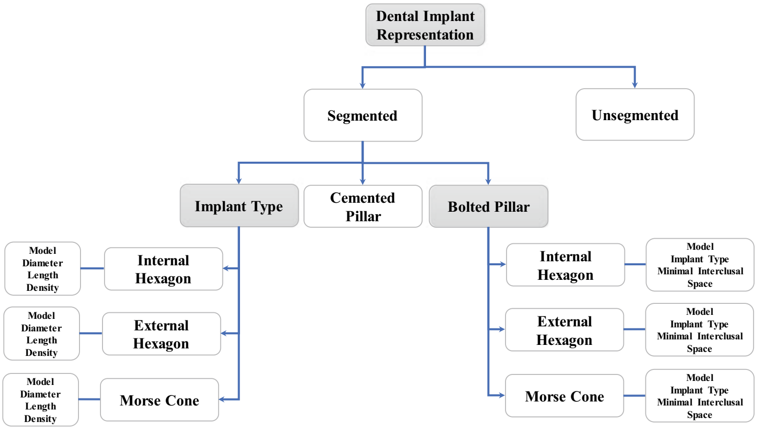


(a) *DFDImplant* Conceptual View

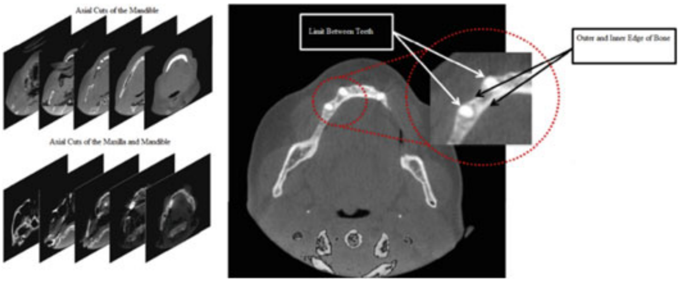


(b) Product Model Representation Structure

Fig. 7.2 DFD implant conceptual structure



(c) Dental Implant Representation Structure



(d) CT sections and interest area in DICOM format

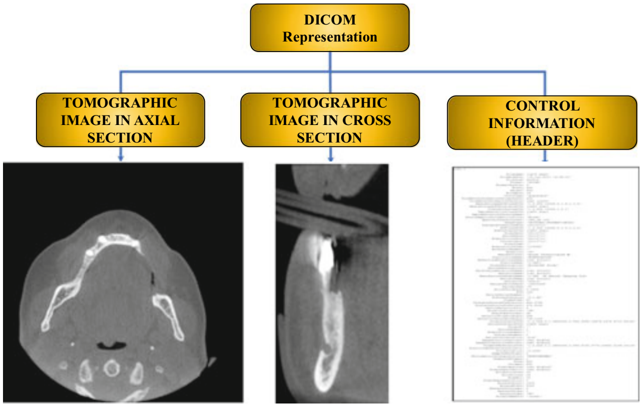
Fig. 7.2 (continued)

requirements, characteristics, machining tools, constraints, materials, among others) in an integrated way.

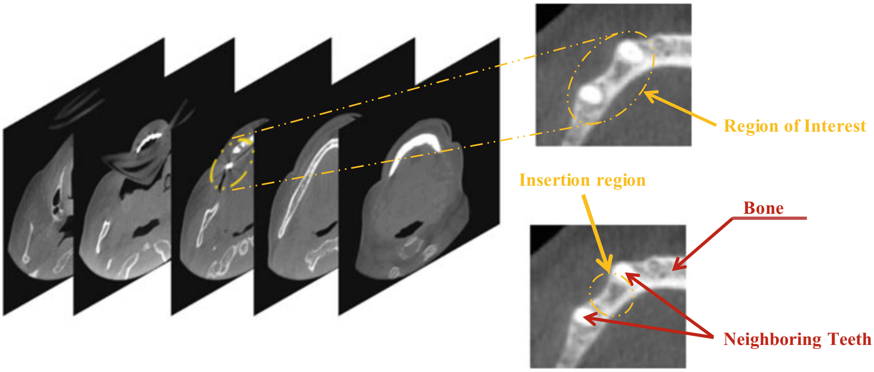
7.5 Product Model

The product model was structured to support the DFDImplant System in the process of conversion, translation and sharing of information between DICOM, Dental Implant and Mask Implant representations. Between DICOM and Dental Implant representations the information must be converted or translated in order to support the "Function 1", and between Dental Implant and Mask Implant the information must be shared in order to Support the "Function 2". This way, the system works with multiple representations, and for this it is necessary to understand how the information contained in one representation will be represented in another representation. With this reasoning, the product model contains the informational requirements necessary for DFDImplant functions, in a structured way. The DICOM representation holds information directly extracted from the computed tomography in the DICOM 3.0 standard, which are:

(i) **Control parameters—**it is the information contained in the tomographic file header obtained in the DICOM standard (Fig. 7.3a—physiological data of the patient, as well as data from the tomographer who performed the acquisition and the parameters of how the images are conditioned in the DICOM standard). For this research, the parameters *Width, Height, PixelSpacing, SliceThickness, Colortype and BitDepth* were used because they guide the system during processing, conversion and translation of the images into information that will be used to analyze the definition of the dental implant;



(a) Axial section, Cross section and DICOM Header file structure



(b) DICOM sections examples

Fig. 7.3 DICOM representation (product model)

(ii) **Tomographic images in axial section—**the information contained in the axial sections guide the delineation of the bone geometry, showing the limits between teeth and between the external bone border and the internal bone border, as can be seen in Fig. 7.3a. With this data it is possible to identify the location of the region for implant insertion and calculate the diameter of the implant that will fit this region. In addition to this information, it is possible, with the delineation obtained by the axial section and the region of insertion of the implant, to generate a transverse section, through the inference conversion mechanism, extracting new parameters from this new image;

(iii) **Cross-sectional CT images—**the cross-section is a section perpendicular to the axial section as illustrated in Fig. 7.3a, generated from a midline between teeth or auxiliary axes created by the dentist in the system for generating the cross-section. The detail of this process is contained in the deduction of the inference mechanisms for determining the cross section. By processing the cross-sectional image, it is possible to determine information such as the length of the dental implant, bone density, location of nerves and check the information of the diameter, obtained when processing images in axial sections.

The representation of the Dental Implant contains the information inherent to the dental implant models (types, diameters, length, among others), which will form the database. In this research, it is being addressed the screwed and segmented dental implant which is composed of 3 parts: (i) prosthesis; (ii) abutment; and (iii) body. The study is focused on the application of the abutment and the implant body, and the handling of the prosthesis will be addressed in future studies. With the information of diameter, length and bone density will be obtained by the inference mechanisms that process the DICOM representation, together with information of the interocclusal region. In this context, Fig. 7.2c presents the conceptual structure for the database of the dental implant representation, to which the expert system, based on the information obtained from CT scans, will select the appropriate group of implants that can satisfy the requirements imposed in each case. This structure presents characteristics of the dental implants such as diameter, length, bone density in which the implants are applicable, besides containing the type and model that are used in the definition of the implant body. Besides this information, this base presents data of the pi-lar, which will fix the prosthesis to the implant body, with its models, type of implant for which they are intended and the minimum interocclusal space necessary for its fixation.

Regarding the type of dental implant, the classification proposed by Misch (2000) was used. From the information extracted from the manufacturer's catalogue, the most important for implant selection are the bone density for which they are indicated, the diameter and the length. Although Misch's classification (2000) presents several models, for this study the internal hexagon, external hexagon and morse cone types were adopted.

The abutment is the element that makes the connection between the implant body, which is fixed on the bone, and the prosthesis located on the surface of the gum tissue.

The selection of the pillar is conditioned by three basic requirements: (i) minimum interocclusal space; (ii) style of prosthesis (single or double); and (iii) type of implant.

7.6 Inference Mechanisms

Inference mechanisms are the elements of an expert system capable of seeking the necessary rules to be evaluated and ordered in a logical way and from there, direct the inference heuristic process (Couto et al. 2007). Thus, the method most applied by this technique is the evaluation of rules, where these must be the knowledge base so that there is the translation, conversion or sharing of information in support of the deployment process. In order to perform the translations, conversions or information sharing information between DICOM, Dental Implant and Guide Mask representations, these mechanisms were structured in three basic functions: (i) Determination of the Dental Implant (Function 1—Fig. 7.4a); (ii) Planning of the Dental Implantation Process (Function 2—Fig. 7.4b); and (iii) Guide Mask Design (Function 3—Fig. 7.4c), as illustrated in the conceptual model (Fig. 7.2a). It should be noted that in this chapter only the exploration of the inference mechanisms related to "Function 1" of *DFDImplant* will be documented.

7.6.1 Inference Mechanisms for Determining the Dental Implant—Function 01

Function 01 has inference mechanisms capable of determining the most suitable set of dental implants based on the extraction or capture of information contained in the patient's DICOM Representation. This information is fundamental for determining: (i) the adequate diameter of the implant; (ii) the adequate length of the implant; and (iii) the bone density for determining the type of thread of the implant. The mechanisms were divided into two parts: (i) determining the body of the dental implant, and (ii) determining the abutment.

7.6.1.1 Determination of Adequate Implant Diameter

The implant diameter is calculated from the geometric information of the symmetry axis S(x), the reference lines PR1(x) and PR2(x) and the bone and teeth borders. For edentulous patients, only the bone thickness existing in the region where the implant is inserted is considered, whereas for partial edentulous patients it is necessary to evaluate bone thickness and the distance between teeth, using the smallest measure obtained between these two parameters. The bone thickness is determined by means of two points obtained between the intersection of the symmetry axis and the external

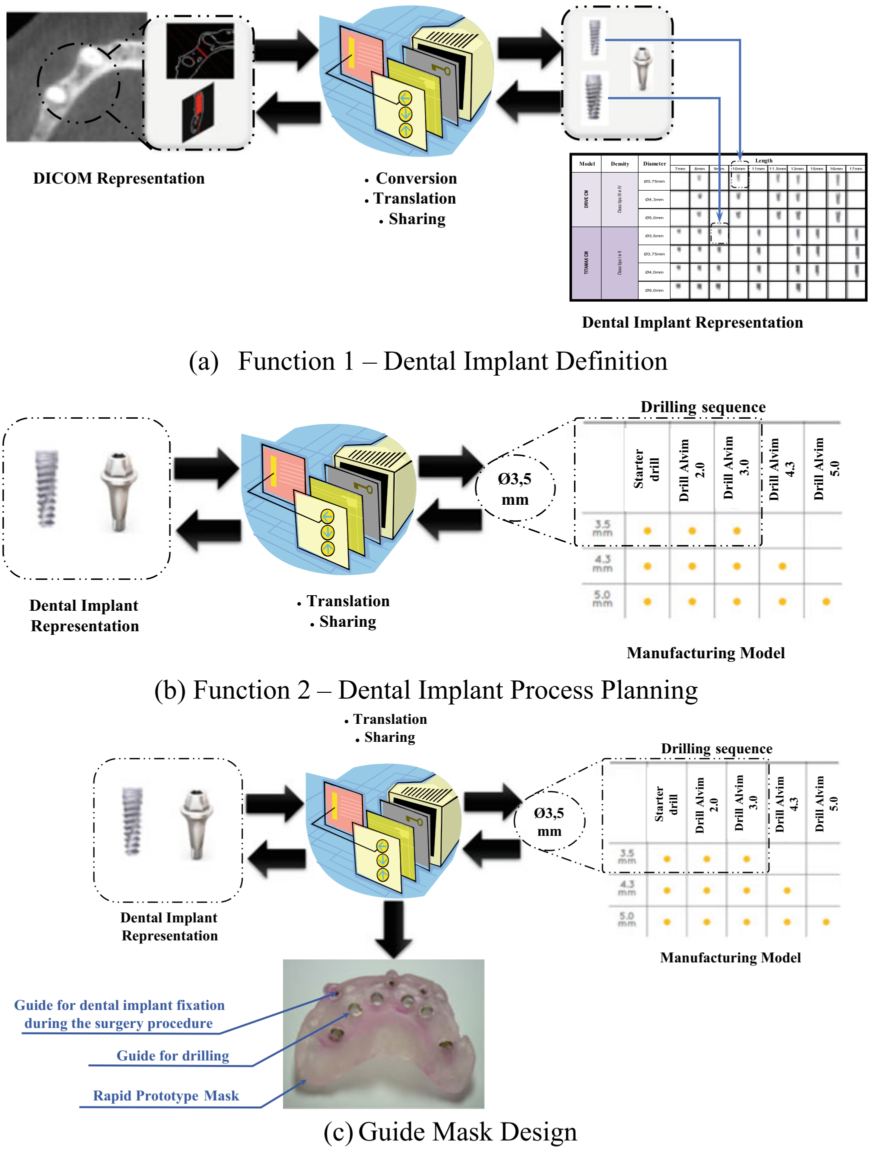


Fig. 7.4 Inference mechanisms

and internal borders of the bone PI1(x,y) and PI2(x,y) as illustrated in Fig. 7.5a and applied to Eqs. 7.1 and 7.2 respectively, obtaining the values in mm.

$$thickness = \sqrt{(PI2x - PI1x)^2 + (PI2y - PI1y)^2}(pixel) \qquad (7.1)$$

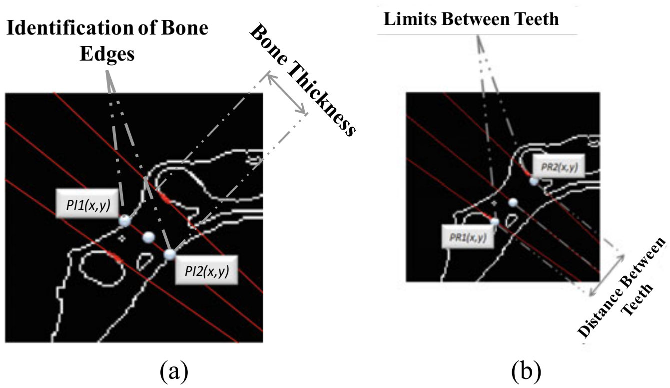


Fig. 7.5 Expert system calculation and plotting for single implant cases

where, PI1x and PI1y are the first points where the line intersects the bone and PI2x and PI2y are the last points where the line intersects the bone and thickness is the bone thickness.

$$ESm = (ESp * PixelSpacing)(\text{mm}) \tag{7.2}$$

where, Pixel Spacing is the measure in mm/pixel of how much the distance of each pixel is worth and thickness in mm is the bone thickness in mm, *ESm* is thickness in millimetres and *ESp* is thickness in pixels.

In the case of partial edentulous cases where there is a need to investigate the distance between neighbouring teeth, the auxiliary straight lines (PR1(x) and PR2(x)) are used to determine the distance that the centre of the insertion is in relation to the neighbouring teeth, i.e., how far the centre of the insertion is from the auxiliary straight lines. Thus the distance between teeth can be obtained by means of a straight line perpendicular to the symmetry axis, according to Eq. 7.3, at the insertion point of the implant, whose straight line will intersect the reference straight lines PR1(x) and PR2(x) as illustrated in Fig. 7.5b

$$SP(x) = mx + (y_0 - mx_0), \text{onde para ser perpendicular m} = \frac{-1}{\text{b}} \tag{7.3}$$

With the straight line perpendicular to the axis of symmetry, its intersection with the reference straight lines PR1(x) and PR2(x) is verified. By solving a linear system of equations obtained by SP(x) and PR1(x), Eq. 7.4, and SP(x) and PR2(x), Eq. 7.5, the points of intersection × 1,y1 and × 2,y2 are obtained, enabling the calculation of the distance between teeth.

$$\begin{cases} (y_0 - mx_0) + mx = SP(x) \\ a + bx = PR1(x) \end{cases} \tag{7.4}$$

$$\begin{cases} (y_0 - mx_0) + mx = SP(x) \\ a + bx = PR2(x) \end{cases} \tag{7.5}$$

where, SP(x) is the equation of the line perpendicular to the symmetry axis and PR1(x) and PR2(x) are the reference lines to the symmetry axis and through Eq. 7.6 it is possible to obtain the distance in pixel between the teeth.

$$\begin{aligned} DDp &= \sqrt{(x2 - x1)^2 + (y2 - y1)^2}(pixel) \\ DDm &= DDp * PixelSpacing(\text{mm}) \end{aligned} \tag{7.6}$$

where, *DDp* is the distance between teeth in pixel and *DDm* is the distance between teeth in millimetres. From the bone thickness and the distance between teeth it is possible to determine the diameter of the implant to be used.

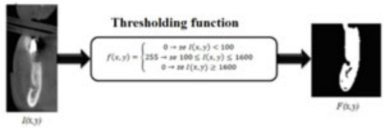
If the bone thickness is smaller than the distance between teeth, the thickness will be used as a parameter to determine the implant, but if the distance between teeth is smaller, the distance between teeth will be used, as shown Fig. in 7.4. The diameter will be determined by the bone thickness or the distance between teeth minus 2 mm, because according to Brink et al. (2007), Lee et al. (2005) and Mahon et al. (2000), the implant should be wrapped with at least 1 mm of surface around it.

7.6.1.2 Determination of Adequate Implant Length

The inference mechanism for the length calculation must analyze and translate the information contained in the cross-section by analyzing the bone depth. This calculation determines the length of the body of the dental implant based on the geometry of the bone and on the location of the nerves when necessary. The location of the nerves is fundamental, as any sizing error can cause irreversible lesions. As in the definition of the bone geometry in the axial section, the bone contour in the cross section follows the same thresholding procedure, where the image is thresholded to a band and unnecessary information is excluded, obtaining only the detail of the bone, as illustrated in Fig. 7.6.

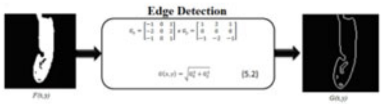
However, although the thresholding extracts information from the bone (Fig. 7.6a), it is also possible to obtain information from the nerve, because according to Table 7.1 (next item) of the Hounsfield scale, the nerve can range from 20 to 40Hu, and in this range the value obtained in the thresholding will be 0 (null), i.e., black, meaning that the nerve is located within the bone and preventing the implant from intercepting the nerve (Fig. 7.6b).

From the image illustrated in Fig. 7.6c (x,z), when applying the edge detection technique using the mathematical simplification model proposed by Sobel, the bone contour and the nerve contour are extracted from the image, which will allow determining the maximum length allowed for the implant. With the outlined bone contour

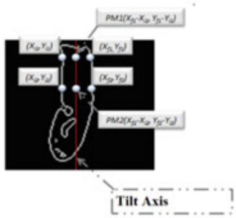


(a) Thresholding function

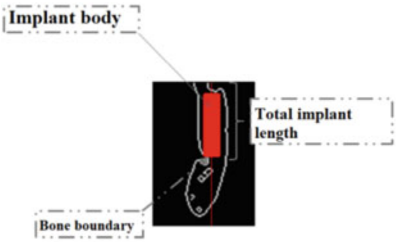
(b) image with nerves location



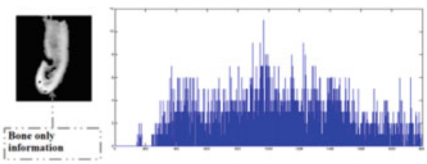
(c) Bone edge determination



(d) Determination of the axis for implant positioning



(e) Determination of the maximum implant length



(f) Cross-section and bone density graph

Fig. 7.6 Information for calculating the implant length

Table 7.1 Bone density classification

Bone	Density
D1	>1250 HU—Dense cortical bone
D2	= 850 to 1250 HU—Thick cortical bone, dense to porous at the ridge of the ridge and thin trabecular bone inside
D3	= 350 to 850 HU—Thin porous cortical bone at the rim involving thin trabecular bone
D4	= 150 to 350 HU—Thin trabecular bone
D5	<150—Non-mineralized immature bone

and the highlighted nerves it is possible to safely determine the length of the implant that can be inserted in the region, but for this to occur it is necessary to create an axis of orientation or inclination of the implant, which will be the midpoint between the edges of the bone. This axis is represented by a straight line, named EI(x), obtained by two midpoints PM1(x,z) and PM2(x,z), allowing the construction of the inclination axis, as illustrated in Fig. 7.6d.

The axis of inclination axis will be used as a reference to determine the length of the implant, because when traversing the straight line $EI(x) = a + bx$ with the im-plant diameter in the Z-axis, from 1 to the limit of the Z-axis, it is possible to visually check that the implant does not exceed the bone border or intercept the nerve (Fig. 7.6e). Should one of these conditions occur, the implant body length will assume the current Z-axis position. After converting the pixel unit to millimetres (Eq. 7.7), 1 mm should be deducted due to the osseointegration process, as recommended in the literature (Brink et al. 2007; Lee et al. 2005; Mahon, Norling and Phoenix 2000).

$$Cm = (Cp * \text{Slice Thickness}) - 1\text{mm} \tag{7.7}$$

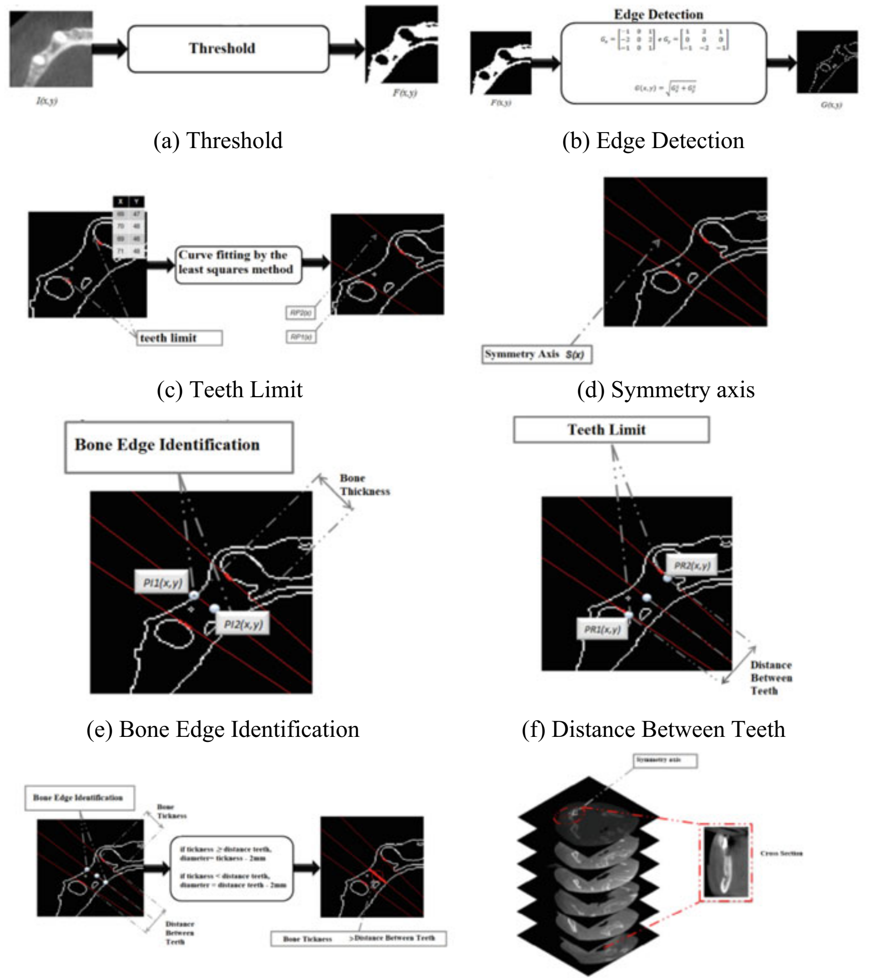
where Cm is the length in millimetres of the implant, Cp is the compression in pixels and Slice Thickness is the ratio between the distance between the pixel in millimeters.

7.6.1.3 Inference Mechanism to Determine the Transversal Section

For the determination of the implant body it is necessary to obtain from the DICOM representation the diameter, the length and the density. The diameter is obtained through the geometry of the bone by axial sectioning. As it is not possible to obtain the length and bone density of the insertion region using only the axial section, in this particular case an auxiliary section is needed, the cross-sectional section, which enables the extraction of this information. To determine the cross-section, the straight line of the symmetry axis is used to generate a plane named WZ, where W is formed by the equation of the straight line of the symmetry axis and Z is formed by the axial sections (varying from 1 to Z), as illustrated in Fig. 7.7. From this plane, information from the tomographic image will be extracted to compose the image of the transverse section named f(x,z). The limits of the axial section image are obtained in the control information (header) in the variable width (X) and height (Y) and in the filename is obtained the number of existing axial sections (Z).

7.6.1.4 Determination of Bone Density

Bone density calculation is the inference mechanism that identifies the type of dental implant appropriate for the bone where the implant body will be inserted. The density is obtained using the histogram of the bone H(x), which for-names the frequency that each intensity value appears in the image. In this research the intensity level followed



(a) Threshold (b) Edge Detection

(c) Teeth Limit (d) Symmetry axis

(e) Bone Edge Identification (f) Distance Between Teeth

(g) Bone Edge Identification (h) Symmetry Axis

Fig. 7.7 Expert system calculation and plotting for single implant cases

the scale proposed by Hounsfield, and based on Table 7.1, which presents the intensity ranges that each type of bone fits into, it is possible to obtain the bone density of the image.

In order to apply the histogram it is necessary to extract from the original image I(x,y) only the bone information, thus similar to the bone geometry detection procedure, when performing the thresholding process, from the original image f0(x,y), the information which fits in the bone range is searched (Table 7.1). Thus, a new image named Iosso(x,y) is obtained, whose values fit only the bone range. This way, the other information is excluded from the image, allowing the histogram H(x) process of this image, as illustrated in Fig. 7.6f.

After applying the histogram technique it is possible to calculate the bone density through the summation of the intensities that are in the range of each bone type (Table 7.1) and Eq. 7.8, where the bone type that presents the highest summation value is the predominant bone type with its respective calculated density.

Adapted from Misch (2000).

$$D1 = \sum_{i=1250}^{1600} H(i),$$
$$D2 = \sum_{i=850}^{1249} H(i),$$
$$D3 = \sum_{i=350}^{849} H(i),$$
$$D4 = \sum_{i=150}^{349} H(i),$$
$$D5 = \sum_{i=0}^{149} H(i), \tag{7.8}$$

where the equations described in Eq. 7.8 are the rules for determining bone density levels, corresponding to the classification proposed in Table 7.1.

7.6.1.5 Mechanism for Determining the Implant Abutment

The definition of the implant abutment is based on an inferred comparison mechanism, since the information required for determining the abutment (interocclusal region, implant type and implant modality—single or multiple) is obtained from previous processes or provided by the oral and facial surgeon. Therefore, the selection of the implant abutment is basically a search on the dental implant representation, whose implant abutment models must meet the stipulated requirements (Fig. 7.4). In the case of the interocclusal region, it is not possible to define the implant by direct comparison, since the implant body and abutment supplier requires a minimum space for fixation in the patient's bone structure.

7.7 Double Failure Dental Implants

The Systematic Literature Review (SLR) and Content Analysis (CA) conducted by Tinfer et al. (2020) identified that there are studies addressing the decision support process. However, most of these studies focus on the solution of cases in an individualized manner, and with this, pointing to the need to develop methods or conceptual approaches for decision support in the process of dental implants with multiple failures. To this end, it is necessary to take into consideration the size of the failure, the bone structure, and the location in the lower nerves by means of computerized tomography image processing, providing the dental surgeon with a better basis for performing the implantation process. Basically, in the RSL and CA showed that: (i) product models are inserted in 75% of the articles considered relevant; and (ii) digital image processing proved important, as 81.25% if was based on the surgeon's decision using the CT scan analyses and the clinical condition variables.

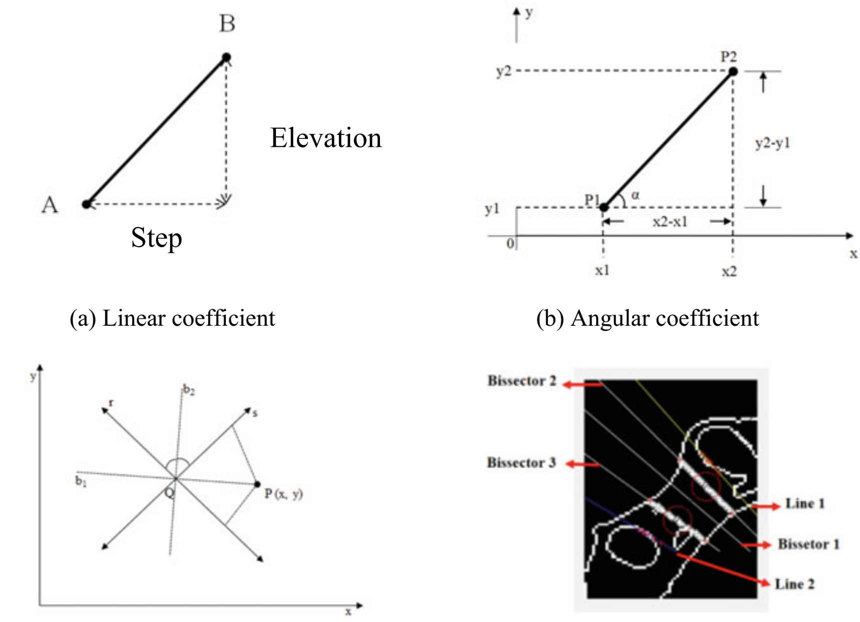
The process variables were defined on the basis of the characteristics found in the definition of the state of the art, where it was possible to identify variables relevant to the process: (i) the diameter and length of the implant as significant variables in the process, because it is through these that it is possible to identify the spacing between teeth and thus calculate the size of missing teeth in the development of a systematic protocol to support the surgeon in the implantation process (Lin et al. 2010); and (ii) bone density, to determine the type of bone, as it is through the analysis of the patient's bone structure that it is possible to identify which are the options for fixing the dental implant and consequently the implant stability. In the state of the art it was possible to identify that 43.75% of the resulting studies took this variable into account. Ribeiro Rotta et al. (2011) worked with the definition of bone tissue characteristics and methods of planning and placement of the implant, whereas Luangchana et al. (2015) proposed a software bone analysis to better support the surgeon's decision in the process.

Based on content analysis and conceptual proposal it was possible to identify that the authors address issues of product model, the information is used by surgeons to assist in the process and how the concept is explicit in the method. It was possible to identify that none of the articles addressed all the processes simultaneously and, therefore, the need arose to develop a conceptual method to support the process of dental implants.

7.7.1 Calculating Symmetry Through Lines

To determine the straight line of the bone edge, mathematical concepts were used, as the straight lines in a plane present their algebraic form in relatively simple equations, being deduced from their angular coefficient. To determine the equation of the line that passes through the points marked on the edge of the bone, the angular and linear coefficients of the line must first be calculated.

For the determination of the linear coefficient the system identifies the coordinates of the points (start and end), identifying a line segment. The horizontal distance between points "A" and "B" is called step (Fig. 7.8a) and the vertical distance between the points is called elevation (Fig. 7.8a). The ratio of elevation to step is the determination of the angular coefficient of the line (Fig. 7.8b), traditionally called m,



(a) Linear coefficient

(b) Angular coefficient

(c) intersection point "Q" between two straight lines

(d) Bisector representation

Fig. 7.8 Bisector calculation

therefore by definition the coefficient of the line present in the image and the plotted points is calculated by calculating Eq. 7.9 (Angular Coefficient).

$$\text{Angular coefficient} = \text{m} = \frac{\text{elevation}}{\text{step}} \tag{7.9}$$

Therefore within the Cartesian system and the line segment plotted by the points we have the points P1 (×1, y1), P2 (×2, y2) and so on with de-more points as illustrated in Fig. 7.8b. In trigonometric language “**α**” is the angle of inclination that the line makes with any horizontal axis measured counterclockwise and “**m**” is the trigonometric tangent of this angle to calculate the linear coefficient of the line (Eq. 7.10).

$$\text{m} = \tan \propto \tag{7.10}$$

Thus, the system will calculate the angular coefficient of the line based on the ratio of the variation of y by the variation of x. With the coordinates of the plotted points, using two points for calculation, by the property of calculating the angular coefficient arrived at the Eq. 7.11.

$$\frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \therefore y - y_1 = \frac{y_2 - y_1}{x_2 - x_1} * (x - x_1) \tag{7.11}$$

As we first identified the slope m and the plotted point of the line, we arrived at the following result shown in Eq. 7.12. Then substituting the point, we arrived at the angular equation of the line, and organizing mathematically we arrived at the reduced equation of the line 7.13.

$$y - y_1 = m * (x - x_1) \tag{7.12}$$

$$y = ax + b \tag{7.13}$$

Thus, the system identifies the coordinates of each plotted point, calculates the angular and linear coefficient and stores the straight line functional, repeating the process with the points plotted on the other tooth edge and calculating the angular and linear coefficient and storing the straight-line function 2.

7.7.2 Intersection Point of the Lines

To identify the point of intersection of the lines, the expert system determines the point of intersection using the equation of each line identified in the previous step, solving the system formed by the two equations (e.g., the lines r: 2x + y-4 = 0 and s: x–y + 1 = 0), gives the solution of the system according to Eq. 7.14. Therefore, the point of intersection of the lines used in this example is P (1,2), so the software calculates the point of intersection of the two plotted lines. To divide the dental gap and ensure the symmetry of the patient's mouth, the software separates the section according to the bisector calculation. To calculate the intersection point, it is necessary to calculate the bisector line to identify each area destined for each implant (Fig. 7.8c).

$$\begin{aligned} &\begin{cases} 2x + y - 4 = 0 \\ x - y + 1 = 0 \end{cases} ; \begin{cases} 2x + y = 4 \\ x - y = -1 \end{cases} \\ &3x = 3 \therefore x = 1 \\ &1 - y = -1 \therefore y = 2 \end{aligned} \tag{7.14}$$

Conceptually, consider two competing straight lines *r: a1x + b1y + c1 = 0* and *s: a2x + b2y + c2 = 0*, which intersect at a point Q. If any point P (x, y), P $\neq$ Q, equidistant from r and s, then p belongs to the bisector of the angle formed by the lines r and s (Fig. 7.8d). Considering the positive sign, we obtain the bisector and considering the negative sign we obtain the other bisector which are perpendicular to each other. The software calculates the first bisector to divide the failure environment into mathematically correct spaces and then repeats the process in each section to find the centre of each implant, plotting the bisector to the user.

7.7.3 Implant Determination (Diameter, Length, Density and Cross Section)

To determine the diameters, lengths, densities and cross-sections of the implants, for double failure, they are calculated individually using the same calculations used for single failure. From the point of view for determining the implant diameter, the system first calculates using the parameters of line space1, bisector1, bisector2, taking into account the central axis of the implant and the tooth thickness, discounting 1 mm on each side to consider the osseointegration of the first implant. Then, the process is repeated for the second implant, using line2, bisector1, and bisector3, also discounting 1 mm on each side to consider osseointegration of the second implant.

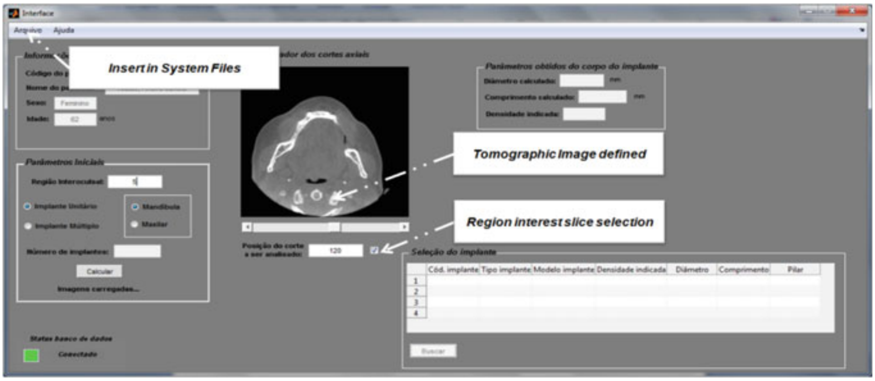
The cross-section is calculated based on bisector lines 2 and 3, presenting complementary information to that identified in the axial section of the image. The system calculates by repeating on bisector axis 2 for implant 1 and then on bisector axis 3 for implant 2.

To determine the length of each dental implant, the system considers the cross-section generated in the previous section, first for implant 1, repeating the process for implant 2, identifying whether the diameter of each implant intersects any inferior nerve or the length of the bone of each implant.

To calculate the bone density, the system performs the independent calculations for each implant defining the bone geometry and classifying the bone type, repeating the process for each implant location to be implanted and determining the bone density according to the classification presented by Misch (2000).

7.8 Case Studies

For the test and evaluation of the method, a prototype computer application (software) was developed on the *Matlab* platform from *Mathworks* (Fig. 7.9a), where the conceptual models were converted and programmed in this interface, with the intention of validating the inference models obtained. This system links the classes and subclasses of the product model to the inference mechanisms through functions and connections (in the case of the connection, with Oracle's *MySQL* database), supporting the whole process of translation, conversion and sharing for the determination of the dental implant. In this section the application of the method in three real cases is being presented: (i) the first case is a partial edentulous patient with a single failure in the mandible in the region of the canine; (ii) the second case is a total edentulous patient with a failure in the region of the maxilla; (iii) the third case is a patient with a double failure in the maxilla.



(a) Experimental systems developed (software)

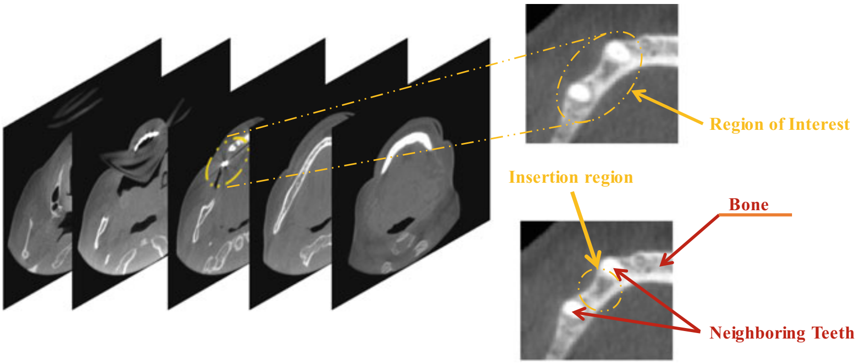
(b) Single failure

Fig. 7.9 Experimental systems and CT emphasizing a single dental fault

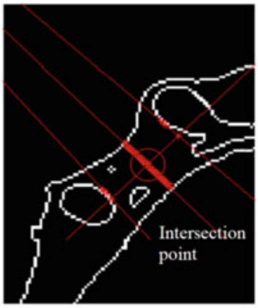
7.8.1 Experimental Case I—Single Mandibular Dental Implant

In test case 1, the patient has a partial mandibular dental defect in the left canine region as illustrated in Fig. 7.9b. With the aid of the dental implant process-oriented design system, it is desired to determine the set of implants (body + abutment) that best suits this patient.

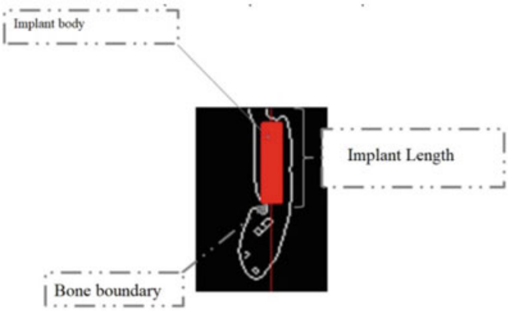
The tomographic images obtained from the patient were inserted into the prototype software, where initially the image that best represented the region of the implant to be inserted was located. Figure 7.10 shows the steps for determining the dental implant, identifying the region of interest and defining the points that outline the edge of the teeth surrounding the region of implant insertion, detail A. From this information the symmetry axis is generated, which allows defining the insertion point of the implant and its diameter, presenting the cross-sectional image generated from the axial slice images, thus allowing analysing the image from another perspective and



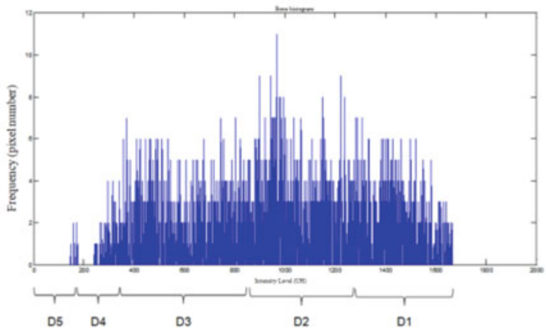
(a) Tomographic sections and region of interest



(b) Symmetry axis and implant diameter



(c) Implant length



(d) Histogram for determining bone density

Fig. 7.10 Logic for determining the dental implant determining the length of the dental implant. Finally, the bone density is presented by the histogram method and the identification of the type of bone this patient presents, as shown in Fig. 7.10d.

By running the models through the expert system prototype, the following results were obtained on the tomographic image inserted into the system:

- Implant body diameter: 3.85 mm
- Length of the implant body: 13.5 mm
- Bone density of the region: D2.

From these parameters obtained in a calculated way, it selected in a database, built from data extracted from a manufacturer, the implants that best fit these characteristics. The expert system is able to create an axis of symmetry between the two teeth through interaction with the user (Fig. 7.10b). This axis is precisely generated as it is based directly on the image, which has an uncertainty of 0.25 mm, which can be considered insignificant from an implantology point of view. Furthermore, this system is capable of defining the implant diameter based on bone thickness or on the distance between teeth, i.e., it uses the smallest distance obtained by these two units to calculate the diameter (Fig. 7.10b).

To determine the length of the implant (Fig. 7.10c) the system uses the contour of the lower bone when it is the mandible and the upper bone when it is the maxilla, as well as the positioning of the nerves, because these limit the measurement of the depth of the hole where the implant will be inserted. For this case where the dental fault has the space for a single tooth, the system calculates the position, diameter, depth and density appropriately (Fig. 7.10b, c). This will not be true when the gap has space for two or more implants. By the rules currently implemented in the system presented as a result **eight** possible implants for this specific case as described in Table 7.2. However, it is believed that if the basis of the criteria for choosing the implant is improved in terms of accuracy, these options will tend to be reduced.

7.8.2 Experimental Case II—Maxillary Dental Implant

In the experimental case II, the patient has total edentulousness of the jaw and it is desired to determine the dental implant for the region of the left lateral incisor with the help of the design system oriented to the dental implant process. This experimental case differs from the previous one, since the patient is edentulous and the expert dental implant-oriented design system uses the teeth as reference, it is up to the dentist-surgeon in this situation to determine the region of insertion of the dental implant. The region of interest was identified and the points that outline the edge of the teeth surrounding the region of insertion of the implant were defined. From this information is generated the symmetry axis that allows calculating the insertion point of the implant and the diameter that it can have after analysing the bone distance and the distance between teeth. With the execution of the models through the prototype

Table 7.2 Implants selected by the specialist system—case I

manufacturer code	Implant body type	Implant body model	Bone Density	Implant body diameter	Implant body length	Implant pillar model
109.616	Morse cone	Titamax CM	2	3.5	11	Pillar cm
109.617	Morse cone	Titamax CM	2	3.5	13	Pillar cm
109.609	Morse cone	Titamax CM	2	3.75	11	Pillar cm
109.610	Morse cone	Titamax CM	2	3.75	13	Pillar cm
109.633	Morse cone	Titamax CM	2	4.0	11	Pillar cm
109.620	Morse cone	Titamax CM	2	4.0	13	Pillar cm
109.464	Internal Hexagon	Titamax IIPlus	2	3.75	11	Mini conical pillar II Plus
109.465	Internal Hexagon	Titamax IIPlus	2	3.75	13	Mini conical pillar II Plus

of the expert system, the following results on the tomographic image inserted in the system were obtained:

- Diameter of the implant body: **3.66 mm**
- Length of the implant body: **17 mm**
- Bone density of the region: **D4**.

From these parameters obtained in a calculated way, a database was selected, built from data extracted from a manufacturer, the implants that best adapt to these characteristics, obtaining Table 7.3.

The expert system can create the symmetry axis based on two planes defined by the system user. The implant diameter is conditioned to the distance between the two

Table 7.3 Implants selected by the specialist system—case II

Manufacturer code	Implant body type	Implant body model	Bone density	Implant body diameter	Implant body length	Implant pillar model
109.684	Morse cone	Drive CM	4	3.5	16	Pillar cm
109.629	Morse cone	Drive CM	4	3.5	16	Pillar cm
109.664	Morse cone	Titamax EX	4	3.5	15	Pillar cm
109.665	Morse cone	Titamax EX	4	3.5	17	Pillar cm
109.669	Morse cone	Titamax EX	4	3.75	15	Pillar cm
109.670	Morse cone	Titamax EX	4	3.75	17	Pillar cm
109.660	Morse cone	Alvim CM	4	3.5	16	Pillar cm

planes when this is less than the bone thickness. In this case, the uncertainty remains the same as in the previous case, being 0.25 mm. The depth also follows the same criteria of the previous case. The only difference is that for this study the system needs the user's knowledge to position the planes and determine the insertion position of the implant. It is not possible to generate the positioning of multiple implants, which is a limitation in this specific case.

7.8.3 Experimental Case III—Implante Dentário Duplo no Maxilar

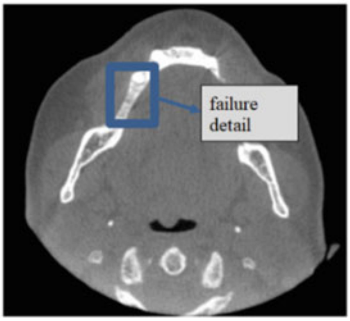
For the case of failure where more than one implant (doubles) will be needed, a case study was carried out with a 70-year-old female patient who presented double tooth failure in the mandible region, as illustrated in the Fig. 7.11a.

The system loads the image in DICOM format through the File/Open buttons, then the user must choose the image slice to be analyzed, select and click on the calculate button. By clicking on calculate, the system processes the image and the user defines the region of interest, that is, the user limits the processing exclusively to the region of tooth failure, as shown in Fig. 7.11a. When selecting the region of interest, the system asks the user to identify at four points the edge of the tooth existing in the two neighbors of the existing fault as in Figs. 7.11c–d. Then the system returns with the calculation of the straight lines, the bisector, then the bisector of each implant, plotting the implant on the screen for the user as shown in Fig. 7.11e. The system in each central bisector of the implant will identify the plane for the cross section as shown in the Figs. 7.12a, b, e.

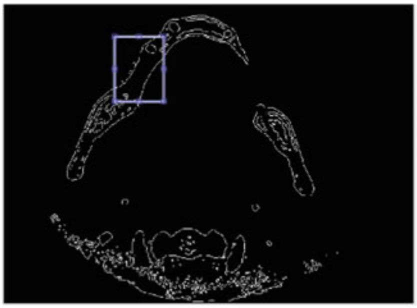
The system returns and calculates the implant length by returning the length plot as shown in Figs. 7.12c–d, later, the system performs the histogram calculation to define the bone type as shown in Fig. 7.12e and finally, the system returns the information to the user, so that it can be compared with the manufacturer's catalog, as shown in Fig. 7.12f and Table 7.4.

7.9 Conclusion

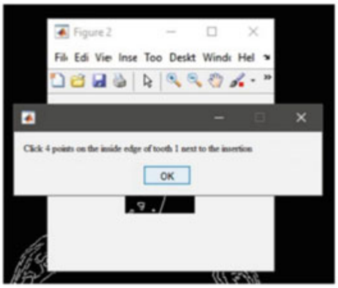
This research presented a proposal for a conceptual model of an expert system oriented to the dental implant process that helps the decisions that the oral facial surgeon needs to take to define the implant that best suits the patient, as in the traditional processes of dental implant the information available for consultation does not provide sufficient support for the correct determination of the implant. This failure in the decision leads to premature fatigue of the implants, prolonged surgical procedures with high trauma and in some situations, the incorrect sizing of the implant



(a) tomography with the region of interest (failure)

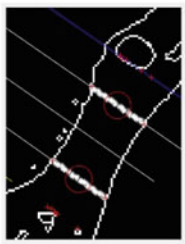


(b) edges of the region of interest



(c) User interface

(d) User interface



(e) Plot of Bisectors and Diameters

Fig. 7.11 Calculation of double implant

body, causing the disruption of the nerves that can cause anything from a partial stoppage of the mouth for a certain time to stoppage total indefinitely.

Thus, we searched through the concepts and techniques in the area of simultaneous engineering, image processing (threshold, edge detection, histogram, arithmetic and algebraic processes) and dental implant (segmented prostheses, two-stage protocol, definitions of implant body and abutment applications) formulate a conceptual design model oriented to the dental implant process, with a product model and inference mechanisms, where the first provides information to the second, which performs the conversion, translation and sharing information in order to determine the implant

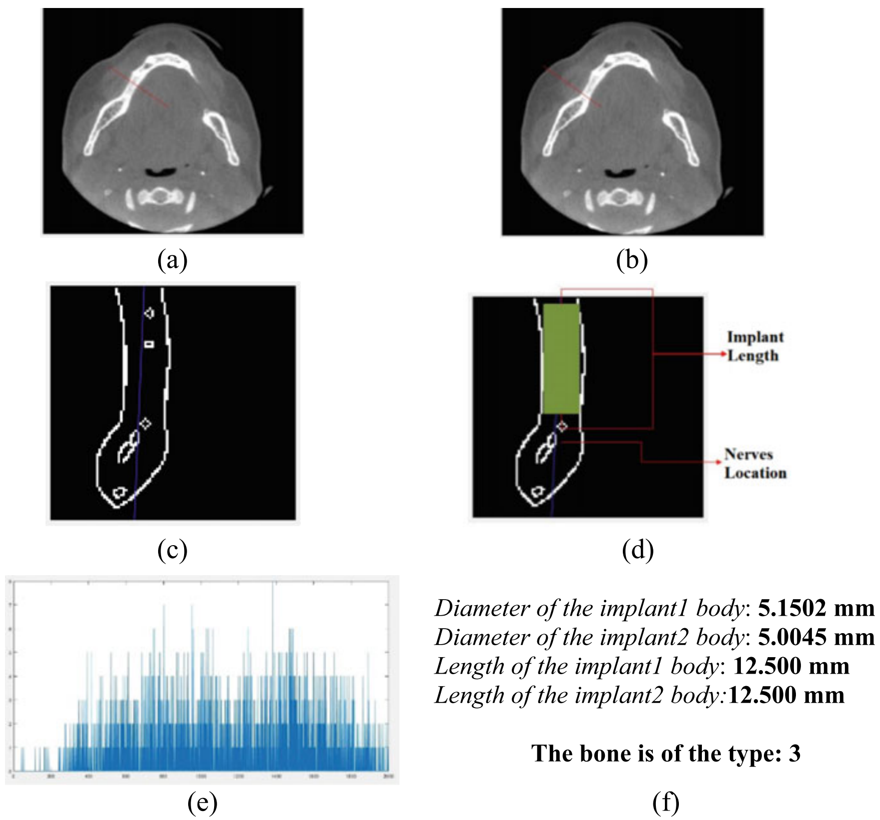


Fig. 7.12 Logic for determining the dental implant

Table 7.4 Implants selected by the specialist system—case III

Manufacturer code	Implant body type	Implant body model	Bone density	Implant body diameter	Implant body length	Implant pillar model
140.953	Morse cone	HelixGM	3	5.0	8	Screwed
140.954	Morse cone	HelixGM	3	5.0	10	Screwed
140.955	Morse cone	HelixGM	3	5.0	11,5	Screwed

that fits the patient's requirements. This conceptual model was implemented in a computer system, resulting in an expert system that presents interactivity with the user and provides, at the end of the inference mechanisms procedures, the indication of a group of sets of dental implants (implant body and abutment) and information subsidy (diameter, length, density, geometry, location of nerves) so that the oral and facial surgeon can choose the most suitable one among these implants. its implementation was developed in a *Mathworks Matlab* environment that allowed the development of the conceptual prototype of the system. Although this implementation presents a user-friendly interface, it is not recommended for professional development, as this research was concerned only with the conceptual side of the models, leaving the interface and the processing time of this system in the background.

Three cases were applied in the specialist system, the first presented a dental failure between two teeth, the second a failure in an edentulous patient and the third was a case of partial edentulous. For all cases, the dimensional uncertainty was in the order of 0.25 mm and this value is not significant from the perspective of implantology. Although the results presented were mostly positive, it is noted that there is a long way to go in order for the system to be able to carry out more complex analyzes than simply a single failure and this should be the object of future research study.

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