Stomatologija, Baltic Dental and Maxillofacial Journal, 10: 67-71, 2008

Creating three-dimensional tooth models from tomographic images

Isaac Newton Lima da Silva, Gustavo Frainer Barbosa, Rodrigo Borowski Grecco Soares, Maria Cecilia Gomes Beltrao, Ana Maria Spohr, Eduardo Golcalves Mota, Hugo Mitsuo Silva Oshima, Luiz Henrique Burnett Jr.

SUMMARY

The use of Finite Element Analysis (FEA) is becoming very frequent in Dentistry. However, most of the three-dimensional models presented by the literature for teeth are limited in terms of geometry. Discrepancy in shape and dimensions can cause wrong results to occur. Sharp cusps and faceted contour can produce stress concentrations, which are incoherent with the reality.

Aim. The aim of this study was the processing of tomographic images in order to develop an advanced three-dimensional reconstruction of the anatomy of a molar tooth and the integration of the resulting solid with commercially available CAD/CAE software.

Methods. Computed tomographic images were obtained from 0.5 mm thick slices of mandibular molar and transferred to commercial cad software. Once the point cloud data have been generated, the work on these points started to get to the solid model of the tooth with Pro/Engineer software.

Results. The obtained tooth model showed very accurate shape and dimensions, as it was obtained from real tooth data with error of 0.0 to -0.8 mm.

Conclusion. The methodology presented was efficient for creating a biomodel of a tooth from tomographic images that realistically represented its anatomy.

Key words: computer aided design, reverse engineering, tooth model.

INTRODUCTION

In the material science, to develop new or any materials, tools are needed to help obtain the expected results. These instruments allow the approach of the ideal design with the best mechanical qualities of the material in development. Dentistry, like other sciences that need constant material improvement, is one that uses technology from material science to reach the excellence in the patient's buccal health treatment. FEA is one of these tools that are constantly used to create or to analyze the odontological materials. This can be seen in works by Sevimay, et al. [1]; Alkan, et al. [2]; Eskitascioglu, et al. [3]; Himmlová, et al. [4]; Yokohama, et al. [5]; Dejak, et al. [6]; Hansson & Werke [7]; Lang, et al. [8]; Simon, et al. [9]; Watanabe, et al. [10]; Lin, et al. [11], among others. Bathe [12] gives an account of the finite element that is one of the most frequently used methods in stress analysis. And he also emphasizes that the results of the FEA computation depend on many individual factors, such as material properties, boundary condition, interface definition, and also on the overall approach to the model. Geng [13] says that the properties of the materials include density, Young's modulus and Poisson's ratio. However, many 3-dimensional FEA studies do not reproduce the real anatomic design of dental element, or consider all the dental components homogeneous, isotropic and linearly elastic. In these cases the results give us only an approximate idea, not the real data. So it is important to see that some distortion or erroneous information in the mechanical models will be decisive in the success tax rates of odontological treatment. With real information we can develop better materials in all dentistry areas, such as prostheses, endodontic, implant, like others too.

---

[1] *School of Mechanical Engineering, Pontifical Catholic University (PUCRS), Porto Alegre, Brazil*
[2] *School of Dentistry, PUCRS, Porto Alegre, Brazil*

Isaac Newton Lima da Silva[1] *– M.E., MS, PhD, assoc. prof.*
Gustavo Frainer Barbosa[2] *– DDS, MS*
Rodrigo Borowski Grecco Soares[1] *– M.E.*
Maria Cecilia Gomes Beltrao[2] *– DDS, MS, PhD, assoc. prof.*
Ana Maria Spohr[2] *– DDS, MS, PhD, assoc. prof.*
Eduardo Golcalves Mota[2] *– DDS, MS, PhD, assoc. prof.*
Hugo Mitsuo Silva Oshima[2] *– DDS, MS, PhD, assoc. prof.*
Luiz Henrique Burnett Jr.[2] *– DDS, MS, PhD, professor*

Address correspondence to Prof. Dr. Luiz Henrique Burnett Jr., Av. Ipiranga 6681, Faculdade de Odontologia, Porto Alegre, RS - Brazil, Zip 90619-900.
E-mail: burnett@pucrs.br

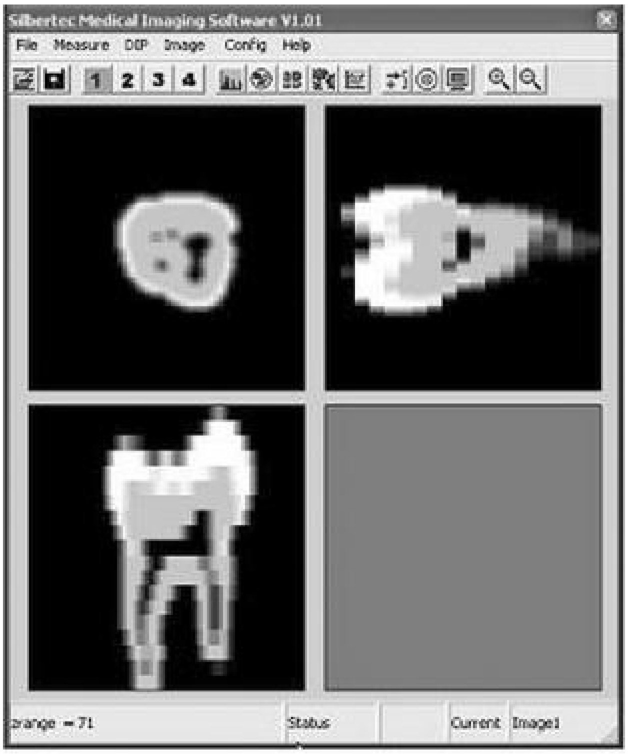

Fig. 1. Tomographic slices

Therefore, the purpose of this study was to create a computerized model of a human dental element with a realistic anatomy. The entire process for obtaining the biomodel is presented here. The methodology could be extended to other models other than a tooth.

MATERIALS AND METHODS

A new software was created (MSI2), which allowed the opening of tomographic images, their segmentation to extract the tooth contour, and the exportation of the relevant information to a format that could be opened by an engineering software. The resulting three-dimensional solid model can be applied to the development of finite element studies of dental implants. The software chosen for this study was the Pro/Engineer WildFire 2.0 (Parametric Technology Corporation (PTC), Needham, MA, USA). The release of the software comes with 55 modules. The modules used in here were the Foundation, used to open the tooth geometric data converted by the developed Medical Imaging Software – MiS2, and REX (Reverse Engineering Extension), which is a partnership with another developer called Raindrop Geomagic (Geomagic Inc, North Carolina, USA), used to create the tooth external surface and, then, the solid.

So, the complete procedure involved the opening the medical images, in DICOM format, extract the points of the tooth boundary, export them to a format compatible with a CAD software, reopen the latter file, containing the point cloud, with the CAD software to then use its RE tools in order to obtain the solid.

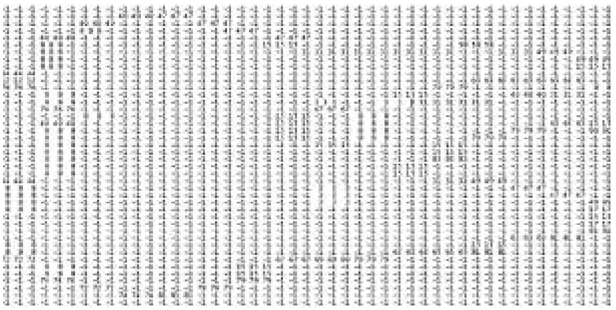

Fig. 2. Contour determination by the Medical Imaging Software

Tomographic images are obtained by tomography (Somatom Plus 4 Volume Zoom, Siemens, Germany) in a certain way that a scanning head, moving in a helical trajectory around and over the length of the object being investigated, collects the data from the various slices with 0.5 mm thick of the object, each slice forming a 2d image with depth resolution equals to the pitch of the scanning head move. The equipment computer stores the data into a file in a non-compressed format.

In order to open the medical images, obtained with the tomographic equipment, the software developed had to be able to retrieve each of the many slices' JPEG images, stored in a sort of database file, called Dicom, which stands for Digital Imaging and Communications in Medicine. In such a file, a composite information object classes contains the patients and the images arrangement information. There, the many images are found and could be read by the software, as any other single JPEG image file would. Internally, the software treated each image as a z element in a xyz array. As the objective was the reconstruction of a solid, out of a number of slice images, the z increment was adjusted to the tomography resolution, and so were the x and y.

With the images stored in a 3d array, the processing was performed by manipulating the array elements. The software has a procedure that can determine whether a pixel on an image under query is an internal, external or a boundary point. It performs a connectivity test in each pixel, assigning a connectivity number to it. The larger this number, the more attached to other internal and boundary points it is. Internal and external point numbers are turned into minus one (-1). Figure 2 shows the result of the application of that routine to a slice image. By just looking at the pattern generated by the different connec-

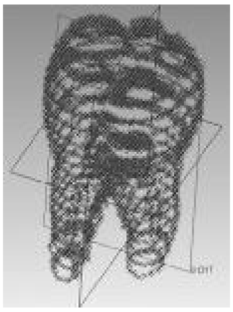

Fig. 3. Point cloud generated by the Medical Imaging Software

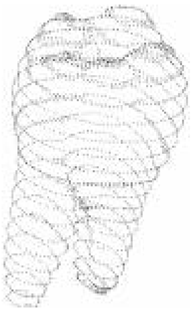

Fig. 4. The point cloud data

Fig. 5. Faceted model before working on it

Fig. 6. Faceted model after working on it

Fig. 7. The solid part with the patches used to create the surface

Fig. 8. The solid part ready for any type of analysis

tivity numbers the shape of the tooth contour can be inferred. The described sequence is repeated to each image in the array and the whole tooth boundary is found. The resulting point cloud was then stored in a file, which could be opened by the engineering software Pro/Engineer, see Figure 3. A point cloud is nothing more than a heap of x, y and z coordinate written in form of text.

Once the point cloud data have been generated, the work on these points could be started to get to the solid model of the tooth with Pro/Engineer. The process of transforming a physical part into a digital model is called Reverse Engineer (RE). A common application of the technique involves copying the real model contour by scanning the part, opening the points in a CAD software, generating a solid out of the scanned points, and making it manufacturable. In this article it was preferred to obtain the points from a tomography, therefore, making the method applicable to any part of a patient's body, and not only a tooth. The part being modeled in that way does not have to be removed from the body in order to be scanned.

Three distinct tasks had to be done in order to get a solid out of the points: the first one involved importing the point cloud file into Pro/Engineer, specifying the coordinate system for their placement and finally using the available tools of the menu "Points" to modify the point set. The second one was to wrap the point set to create a triangulated model and work on the model, if necessary, for removing unwanted triangles, for example. And the third part was the *facet* modeling. A facet model, also called Polygonal Mesh, is a native triangulated model of Pro/Engineer that is created by connecting the points of the data. It was in this last step that the model refinement occurred.

However, it happened that the software generates the point cloud with a bit of noise. Noise, in this case, is a deviation of the points from its original place due to the limitations of the scanning devices or the routine in the MiS2 software that created the cloud. It causes points that do not belong to the data. In order to clean this noise and other undesirable geometry, Pro/Engineer supplies some useful tools.

The *Sample* Icon takes just a sample of the points. It is not necessary and not advisable to work with the whole points because the more points the model has, the more processing time is needed. The *Reduce Noise* tool uses statistical methods to place the points to its correct location. Based on this the level of noise reduction can be chosen and if the geometry of the model is a Free-Form (reduces noise with respect to the surface curvature) or a Mechanical (keeps the sharp corners and edges) shape. Finally, tools are available to delete some points, by just selecting them and simply deleting.

In the wrap the point set stage, the software uses all the points of the point set to create the wrap, which means that all the geometric information, including internal structures, is maintained. After enough work on the points has been done, there was no need to fix anything here, so it was ready now to create the *facet* geometry.

This third phase consists of creating a model that is native to Pro/Engineer. This is called a *Facet* model. Although the model already has mass properties, such as volume and density, it is not possible to run structural and thermal analysis, which are future goals. So, there is the need to refine the facets as much as possible to make them good to be worked with further. For this purpose there are some other tools that change the coordinates of the existing points or add new points to the original set. The *Refine* icon improves the surface of the facet model by making the mesh denser, through subdivision of the existing facets. This results in an increased number of facets in the model. Using this command results in a more detailed and smoother surface. The *Relax* tool smoothes the surface, by moving the coordinates of the facet vertices. The last command exploited was the *Mani-*

fold. A manifold representation of a model has all the triangles connected continuously by their edges except for boundary edges. If a point set represents a closed object, the *Wrap* command creates a closed object. However, noise in the scan data can result in a wrap model that is not closed or contains non-manifold edges, that is, some triangles in the model are not connected continuously by their edges. So there was the need to make the whole facet surface closed.

Now that a model with the extension of Pro/Engineer part (prt) was created, it could be transformed in a solid model to, then, be able to do any type of 3d analysis. But, to do so, some curves and surfaces on the faceted model had to be created. That was done with a tool called *Restyle.* The Restyle module is the Reverse Engineer environment that enables the user to create a surface on top of the faceted feature for later solidification. The auto surface option was used. This tool creates paths along the entire surface of the triangulated data that would be used to build a surface to involve the whole model. Once a continuous surface was created, it could be solidified by just selecting the proper tool icon. This option adds material to the model, by using the surface feature geometry as the boundary, converting it into a solid geometry.

RESULTS AND DISCUSSION

Medical images provide very important information on the body structures and their related disorders. Because of that they are, for some pathologies, the only way of a precise diagnosis. These images can be obtained by a computer tomography (TC) or through a LASER scanner. Available in the Dicom format, the images of the various slices in JPEG format, obtained by scanning the region of interest in the body, carry accurate geometric information of body organs, which can be used to generate three-dimensional models of those structures in a relatively easy way. Either in the TC or in the LASER scanning, the information obtained were a set of points that represents a spatial measurement (in the three coordinate system's axes). These points are saved into a text file and then imported to a computational tool known as CAD (*Computer Aided Design*). Usually this file is called *point cloud.* Once that is opened it is possible to work on it using algorithms of refinement, sampling the points and creating curves and surfaces. As the model has been created, now it is ready to carry through any structural or thermal simulations and even to make a study of a particular surgical case where the surgeon dentist may need to understand and study the situation before starting the surgery. All these analyses can be made virtually with the great advantage of spending less time to get results and not needing laboratories nor the physical teeth.

Reconstructed in that way, the models are very useful for a realistic analysis produced by a CAE software, when designing new implants or surgical procedures. Pileicikiene et al. [14] described a very detailed and similar methodology to create 3D models from mandible, temporomandibular joints and teeth using tomography slices. However, the authors did not describe the solid geometry that is an important step to prototyping. The possibility of developing rapid prototyping parts would aid the implant designers with the verification of accuracy and adjustment of the prosthetic components, for instance.

With the advances in the latest generation of computers, graphical hardware and software, and CAD/CAE software, the use of the finite element analysis became very attractive to many fields, including medical and dentistry purposes.

There are many commercially available CAE softwares that can simulate realistic loads and constraints to produce close to exact results. Those softwares are, in the majority of the cases, integrated with a CAD module, which can be used to enter 3d parts to the simulation. The latest software comes with a variety of designing tools that are quite powerful to model well-behaved shapes, like the ones encountered in the mechanical industry. However, body structures are quite complex in shape and the development of such models with the available software tools can be a very time-consuming and laborious task, not to say almost impossible job. But three-dimensional models are necessary for a realistic finite element analysis, and a way of directly interfacing medical imaging data to a CAE software environment can considerably improve the analysis of dental implants, for instance, by providing very accurate geometric information.

This paper presents a methodology that allows the interface between medical imaging equipment (computer tomography – CT) data and engineering software. This method showed two kind of errors that were present through the whole process of obtaining the solid, the error inherent to the tomographic equipment and the error resulting from the point cloud manipulation by the RE software. Here only the later one could be measured and was taken into account as a means of quantify the inaccuracy of the process. This error was directly measured on the model, using the available tool *Measure>Distance*, considering the model surfaces and the closest points to them in the cloud. That error was found to lie between 0 and -0.8 mm, therefore shortening the model in relation to the real tooth geometry. The reason for that was that the filtering and smoothening routines tend to eliminate the cusps and sharp edges of the wrapped feature. The inaccuracy of the tomography can vary from equipment to equipment and is statistically independent from the software errors. Although these kinds of errors were present through the whole process of obtaining the solid, the magnitude of these errors can be reduced by the decrease of the distance from the slices in JPEG format from the computer tomography.

The advantage of this method, when compared with the LASER scanner method, is the possibility on obtain data from the internal parts of the dental structure; witch is impossible by a LASER scanner method, that only obtains superficial structural details. So it is possible identify the pulp and it respectively canals. It will help us to develop better mechanical tests and, consequently, better materials, because we are being able to define the regions that form the dental complex with its real physical characteristics.

CONCLUSIONS

From the encouraging results obtained in this work, three conclusions could be drawn:

1) The methodology presented was efficient for creating a biomodel of a tooth from tomographic images that realistically represented its anatomy.

2) The model could be utilized for FEA of dental implant designs that would not result in feature-based solid, therefore eliminating the problems of some very common in literature models, which have very sharp cusps and edges, resulting in non realistic stress concentrations.

3) The model errors could be measured, showing a reduction in its dimensions when compared to the real tooth tomographic data. Further evaluation of that effect in the FEA model has to be carried out.

REFERENCES

1. Sevimay M, Turhan F, Kilicxarslan MA, Eskitascioglu G. Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. *J Prosthet Dent* 2003;93:227-34.
2. Alkan I, Sertgöz A, Ekici B. Influence of oclusal forces on stress distribution in preload dental implant screws. *J Prosthet Dent* 2004;91:319-25.
3. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of oclusal loading location on stresses transferred to implant-supported prostheses and supporting bone: A three-dimensional finite element study. *J Prosthet Dent* 2004; 91:144-50.
4. Himmlovą L, Dostįlovį T, Kįcovskż A, Konvičkovį S. Influence of implant length and diameter on stress distribution: a finite element analysis. *J Prosthet Dent* 2004;91:20-5.
5. Yokoyama S, Wakabayashi N, Shiota M, Ohyama T. The influence of implant location and length on stress distribution for three-unit implant-supported posterior cantilever fixed partial dentures. *J Prosthet Dent* 2004;91:234-40.
6. Dejak B, Mtotkowski A, Romanowicz M. Finite element analysis of stresses in molars during clenching and mastication. *J Prosthet Dent* 2003;90:591-7.
7. Hansson S, Werke M. The implant thread as a retention element in cortical bone: the effect of thread size and thread profile: a finite element study. *J Biomech* 2003;36:1247-58.
8. Lang LA, Kang B, Wang RF, Lang BR. Finite element analysis to determinate implant preload. *J Prosthet Dent* 2003;90:539-46.
9. Simon U, Augat P, Ignatius A, Claes L. Influence of the stiffness of bone defect implants on the mechanical conditions at the interface - a finite element analysis with contact. *J Biomech* 2003;36:1079-86.
10. Watanabe F, Hata Y, Komatsu S, Ramos TC, Fukuda H. Finite element analysis of the influence of implant inclination, loading position, and load direction on stress distribution. *Odontology* 2003;91:31-36.
11. Lin CL, Chang CH, Wang CH, Ko CC, Lee HE. Numerical investigation of the factors affecting interfacial stresses in a MOD restored tooth by auto-meshed finite element method. *J Oral Rehabil* 2001;28:517-25.
12. Bathe KJ. Finite element procedures. Upper Saddle River (NJ): Prentice-Hall; 1996. p. 148-377.
13. Geng JP, Tan KBC, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent* 2001;85:585-98.
14. Pileicikiene G, Varpiotas E, Surna R, Surna A. A three-dimensional model of the human masticatory system, including the mandible, the dentition and the temporomandibular joints. *Stomatologija. Baltic Dent Maxillofac J* 2007;9:27-32.

Received: 04 09 2007
Accepted for publishing: 21 06 2008