Digitization procedure of creating 3D model of dental bridgework reconstruction

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Analysis and modelling

ABSTRACT

Purpose: The still growing patient requirements is concerned with aesthetics but also with strength of the prosthetic restorations. Resistance on stresses depends among others on the shape, so it is necessary to transfer the dentures of a physical model to a computer environment and a simulation of the work conditions. The aim of that work was to study the methodology of digitization of a plaster model into a numerical model, using CAD/CAM dental system and CAD application, which can be in a next step imported to ANSYS application in order to realize stress analysis.

Design/methodology/approach: To realize the transfer of a physical model of the dental bridge to a computer environment the 3i Incise Renishaw scanner which saved the plaster model by a probe about 1 or 3 mm diameter, moved in the scanner arm and contacted with it was used. A scanned plaster mode was exported into STL file and then opened in DentCAD Delcam application. Using the CAD module the preparation line was marked, a pontic was orientated in a right position and connectors of the pillar teeth and the pontic. Geometry and the cross section of the connectors depend on the bridgework strength. A designed bridge reconstruction was imported to CAD application and there curves were firstly drawn, then changed into NURBS surfaces and finally surfaces were merged into one solid model. A ready model can be imported up to ANSYS software in order to realize the stress analysis.

Findings: A prepared dental case from a physical one was changed into a numerical model in following steps: scanning a plaster model by a contact scanner, designing the bridgeworks in CAD dental software environment, importing in CAD application, building the solid model and at the end importing in ANSYS software. Selected digitization procedure let to make all engineering calculations and analysis without manufacturing the physical model, what considerably reduce cost of the research investigations.

Practical implications: A realized work gave an information about possibilities of verification for a physical model of restoration and a numerical model which can be compared to results from software simulation of behaviour of the bridgework in different load cases.

Originality/value: The paper presents that it is not necessary to have a physical reconstruction model, to check the resistance on stress because it is possible to use the CAD/CAM dental system to design the dentures and then modelling the boundary conditions and observe the stress analysis.

Keywords: CAD/CAM; Dental bridge; Digitization; Prosthodontia

1. Introduction

The still growing patient requirements concerned with the aesthetical filled tooth supplement, is connected with the knowledge about colours and the transparency of natural tooth and production of the full ceramic dentures made by zirconium oxide [1] using the computer-aided designing (CAD) and computer-aided manufacturing (CAM) systems. In consequence of those given requirements it is necessary to build an aesthetic construction and works which ensure security mounted into a patient.

All those reasons cause that new development trends [2] and scientific research referring to properties of biomaterials used on prosthesis, the mechanical properties [3-5] and also those related with biocompatibility [6,7], corrosion resistance [8] and possibility to implantation to human body (oral cavity), without any complication or allergic interaction on the human organism [9,10] have been appearing.

The settled materials properties used to manufacturing dentures create opportunities to perform state of stress analysis into prosthetics construction. Advanced available computer systems make possible to import into their software the structure of dentures with geometrical characteristics features and then a set of the starting support and forces conditions may show a result of stresses existed in construction and the deformation of each point and all dentures [11].

One of the most important difficulties during performance of a described above analysis is an irregular shape of the dentures rebuilding missing teeth, what causes that this kind of analysis is a very time-consuming method. An evaluation of the state of stress analysis from physical experiments is very expensive and often ethically questionable when performed on alive subjects. In order to obtain satisfactory results, concerning on dimensional accuracy of the realized prosthetics construction, it is necessary to show the tooth anatomical geometry with the highest level of precision [12,13].

The formulation of the virtual numerical model allows to reduce the life and health danger and also that kind of tests realized on a virtual model favours in restricting expenses of research procedures. Optimization of the geometrical design takes place on a computer, especially in a specialized CAD software. Thanks to a very fast evolution in computer and IT technology concerning numerical models many different methods of capturing the shape, geometrical details and receiving 3D body surfaces appear [12,13].

In order to change the physical model to numerical one, it is possible to use for example one of the following methods:

- immersing the preparation of a tooth (premolar) in plastic resin, then cutting on slices and making measurements section by section, getting as results information about a cross section with good accuracy (Fig. 1). Unfortunately, there are some problems with the use of those methods chosen for a very thin section, because in that case the sample may be destroyed. The preparation of samples and realisation of geometrical digitization cause some difficulties and a considerable effort [14,15];
- applying the information about average dimensions of human teeth (Tab. 1), on the basis of which a representative model is built, without an access to any devices or machine. To build individual dentures using this method, it is very difficult to obtain a high level of shape and geometry and to prepare a sketch, geometrical measurement and digitizing extra time

and considerable effort must be destined [12,16,17]. Dimensional information can also be received using a photographic camera and a special computer controller with 5° intervals for a total of 72 images (360°) and with 11 different inclination angles [18];

- geometry of the dentures is saved to a computer software by digitization with the use of a CT (computer tomography) scanner, guarantying the receipt of high precision of a cross section of the structure (Fig. 2). The CT scanner characterized by high speed of transformation from a physical model to a numerical form, describes very good the sample and protection of the work, but it is demanded to have the micro-CT scanner and a specialized software to reconstruct the model [21-23];
- a physical plaster model is changed by a digitization process into a numerical model with a use of a scanner which may work in two different ways. A digital model of dental restoration is created from the contact scanner (inCise-Renishaw, Procera Forte-NobelBiocare, Denti Cam-BEGO) where a probe moving on the plaster model send the data to a computer and save point by point one part of a model. The second possibility to reach a numerical model prepared to a virtual model of the dentures is to use a noncontact, optical scanner which uses different light band frequency (Lava-3M ESPE, Everest-KAVO, inEOS-Cerec) to save pictures as the digital complete model part [25].

A used method of CT scanning to obtain a numerical model and help in solution of biomechanical problems is commonly met in many different medical applications for example: the most interesting dental cases [13,26], cervical vertebra [27] or a human skull [28].

The aim of that work was to study the methodology of digitization of a plaster model into a numerical model, using CAD/CAM dental system and CAD application, which can be then imported to ANSYS application in order to realize stress analysis.

2. Model and methodology

The physical model is made as IV class plaster cast and a sectional model of upper teeth arch is prepared (Fig. 3). On basis of that plaster model, the reconstruction of one missing tooth 22 with a use of double edge fixed prosthesis, supported on two pillar teeth 21 and 23 was planned.

2.1. Scanning model

The first step in the digital modeling is to capture the physical model and save it in a computer system. Surface digitization, design and manufacturing of the dental bridge was realized with the use of CAD/CAM system 3i Incise (Renishaw, UK) company, which is built from two modules (machines): a contacting scanner (Fig. 4) equipment into a holder, Triact mechanism and two contacting probes 1 mm and 3 mm diameter are made of plastic. Incise dental scanner specification are: measuring area: 90 mm diameter and 45 mm height, probe force: 0.5 N/mm, the measuring accuracy 20 μm, scan interval was 0.1 mm and scan speed 600 mm/min. The second module of Renishaw system is a numerically controlled milling machine manufacturing a design of dentures from wax or zirconium dioxide plate [29].
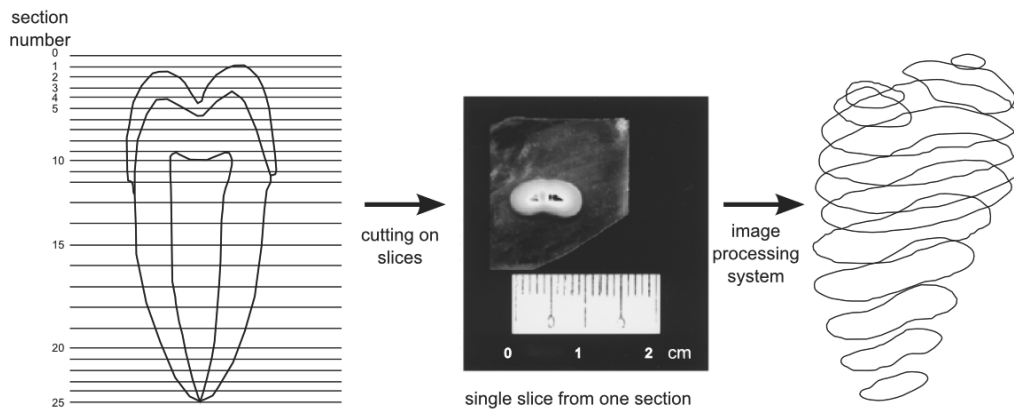
Fig. 1. The diagram of changing methods of a physical model of a tooth on 3D digital model [14]

Table 1.
Human teeth dimensions [19,20]

| Dimensions [mm]	Tooth number							
	11 21	12 22	13 23	14 24	15 25	16 26	17 27	18 28
crown length	10.5	9.0	10.3	8.7	8.5	7.7	7.2	6.0
crown width	8.5	6.5	7.6	7.0	6.9	10.0	9.0	8.5
crown depth	7.3	6.0	8.3	9.7	9.5	11.0	11.0	10.0
width on neck	6.2	5.2	5.8	5.0	5.5	8.0	7.3	6.7
nepth on neck	6.7	5.5	7.5	8.0	8.2	10.0	9.8	9.0
tooth length	23.7	22.0	26.3	21.3	21.3	22.3	20.0	18.3
Dimensions [mm]	Tooth number							
	31 41	32 42	33 43	34 44	35 45	36 46	37 47	38 48
crown length	9.0	9.5	11.0	8.7	8.2	7.7	7.3	7.0
crown width	5.0	5.5	7.0	6.8	7.2	11.0	10.5	10.0
crown depth	6.0	6.5	8.3	8.0.	9.0	11.0	10.3	9.7
width on neck	3.5	4.0	5.3	4.8	5.3	8.7	8.3	8.0
nepth on neck	5.2	5.8	7.7	6.7	7.3	9.7	9.3	8.7
tooth length	20.3	21.7	25.3	22.7	23.0	20.7	19.7	17.0
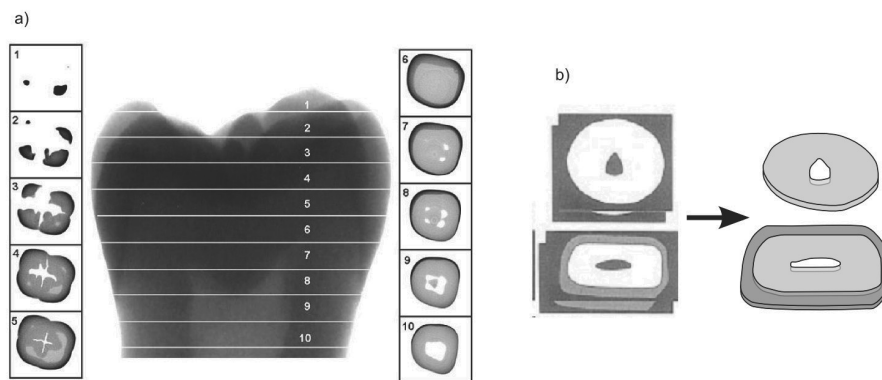
Fig. 2. Process of digitization of tooth using CT scanner and preparation to mesh on finite elements: a) image divided on slices with a cross section of a tooth, b) transfer of each slice on curves and next on surfaces, to prepare a model meshing on finite elements [12,24]
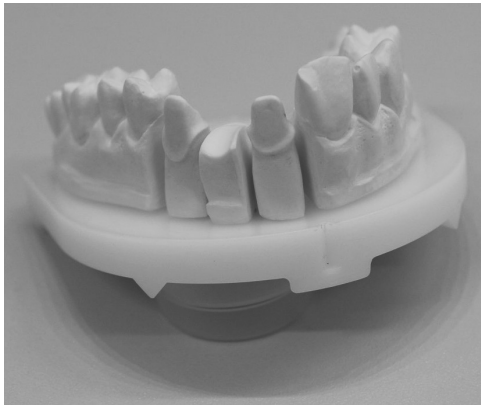
Fig. 3. Plaster model with prepared stumps to a tooth reconstruction

Fig. 4. Dental contacting scanner 3i Incise Renishaw

2.2. Design bridge

A design on scanned and saved in file format STL dentures was realized in DentCAD (Delcam, UK) CAD application, which is integrated with the Incise scanner. The application can import STL file with saved and scanned plaster stumps. Designing process of the bridgeworks using DentCAD may be realized in the following steps: importing the STL file, choosing interesting stumps, drawing a preparation line for all pillar tooth, designing of geometry and orientation of the pontic and the connector surface to the pillar, planing cement gap thickness (occlusal cement gap, siding cement gap, cervical cement gap and cervical cement distance). When the denture is ready it is possible to check the accessibility shading and tool radius shading. Ready work can be exported to file format STL, which is possible to import back to 3i Incise system and send the work to manufacture or read by another CAD application [30].

2.3. CAD application

The CAD application after an import of the file format STL allows to control the model and it is necessary in the first way to realize a kind of repair of geometrical operation such as: adding an element to mesh, closing holes and gaps, removing overlay surfaces, bad cutting surface identification, finding duplicates. During modeling the solid structure from STL mesh some assisting tool are available, for example when on mesh curves are created, Curve stick to triangles mesh, which guarantees that the curve will be each time on mesh surface and give back its configuration may be used. When the mesh is divided by curves series it is possible to create a close loop using composite curves from the existing one. The area restricted by curves may be changed by the use of fill option in NURBS (Non-Uniform Rational B-Spline) surfaces reflecting the mesh body. NURBS surface is the most elastic methods to represent surfaces in a model and it is commonly used in a computer-aided design systems. When all mesh body is filled by surfaces it is possible to connect them and create one solid. Next the solid may be exported as a solid model of file format IGES, DWG or Parasolid works.

3. Results of digitization and designing

Finally the plaster model was prepared and installed in a holder of the 3i Incise scanner, chosen promptly by Incise software application type of a probe and the scan process during which contacting with a model probe causes in a draw point on a computer screen .The model data was captured and built on screen firstly as wire-frame, followed by surface generation and finally fully rendered showing re-entrant data (undercuts, Fig. 5). It is important to control the range of undercuts, for a scanned model it was in good state, but while the undercuts data are localized above, the preparation line should be minimized and when the undercuts area are on preparation line, the scan must be repeated, because it can cause problems when the manufactured reconstruction to natural teeth in patient mouth is tried to be fit. After scanning all necessary stumps ready numerical model (Fig. 6) was saved and exported to file format STL.
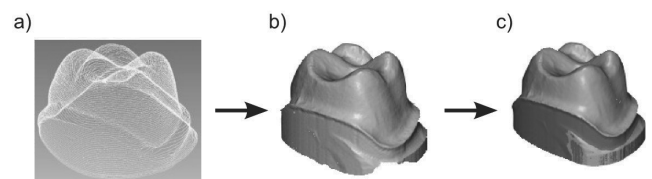

Fig. 5. Scanning tooth stump stages: a) created cloud of points, b) surface generation from points, c) scanned stump with showed undercuts
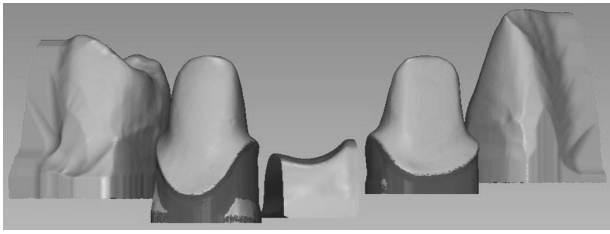
Fig. 6. Ready plaster model with the referential teeth scanned by Renishaw 3i Incise

The next stage was completed after an import of the STL file to DentCAD application and design of the fixed prosthesis. Designing process in the DentCAD consists of three steps: marking a preparation line on 21 and 23 pillar tooth (Fig. 7a), constructing geometry and orienting the pontic tooth in a view with the reference teeth 11 and 24 (Fig. 7b), and editing connectors between pillars and a pontic, by positioned then at a symmetry axis of two pillar teeth (Fig. 7c). A cross section area of the connectors was set at 6.0 mm. Before confirming, the bridgeworks are checked in a point of accessibility shading (Fig. 8a) and three big areas with the shading which will not be machined using the 3i Incice CNC miller, because they work only in 3 axes, were founded. An application also checks tool radius shading (Fig. 8b), which for Renishaw milling machine is 0.55 mm, marked areas means that in those places milling machine cannot remove material and there will leave some small excess material thickness. When both of those parameters are accepted, during generating the milling path CAM application will use approximation of those areas. Finished bridgework from DentCAD (Fig. 7d) was exported to file format STL, ready for being imported back into 3i Incise CAD and manufactured.

In order to realize stress analysis using ANSYS software it is necessary to change the stereolitography file on solid, because original data consists of triangles mesh. All next operations on STL mesh may be done in any CAD application which enable to create the curves and surfaces on the mesh base, like for example: SolidWorks, Autodesk Inventor, Delcam PowerSHAPE starts. After an import of the STL file with abridgework (Fig. 9a), curves which divided the model on each simple part: a pillar, a connector, a pontic, a connector were created. Then from those curves the rest of the curves were built and created a closing part of STL mesh. Then the curves closed loop were changed into NURBS surfaces (Fig. 9b), for the analyses of bridgeworks 42 surfaces were created and the tolerance between match surface to STL mesh was at average 0,03. When on all STL model was created, surface changes them in one solid model (Fig. 9c). A solid model of dental bridge in CAD application prepared by showed methodology can be exported to a file format IGES, DWG or Parasolid works. That kind of file was imported in the ANSYS 12 software (Fig. 10) and prepared to realize the stress analysis.

4. Conclusions

The digitization process applied for all biomechanical application is one of the meaningful role in the creation of the 3D numerical model. A realized work was concerned on the creation of an input file to ANSYS software in order to set the boundary conditions and make possible to perform the stress analysis.

A prepared dental case from a physical one was changed into a numerical model in following steps: a scan plaster model by a contact scanner, designed the bridgeworks in CAD dental software environment, imported in CAD application, built the solid model and at the end import in ANSYS software. Selected digitization procedure let to made all engineering calculations and analysis without manufacturing the physical model, what considerably reduce cost of the research investigations. However when the dental work must use a machine it is necessary to pay attention to all places where can appear undercuts or different shading coming from milling machines production capacities and tool size. The described procedure is a successful method to produce a highly detailed and very good tolerance model used for dental applications.

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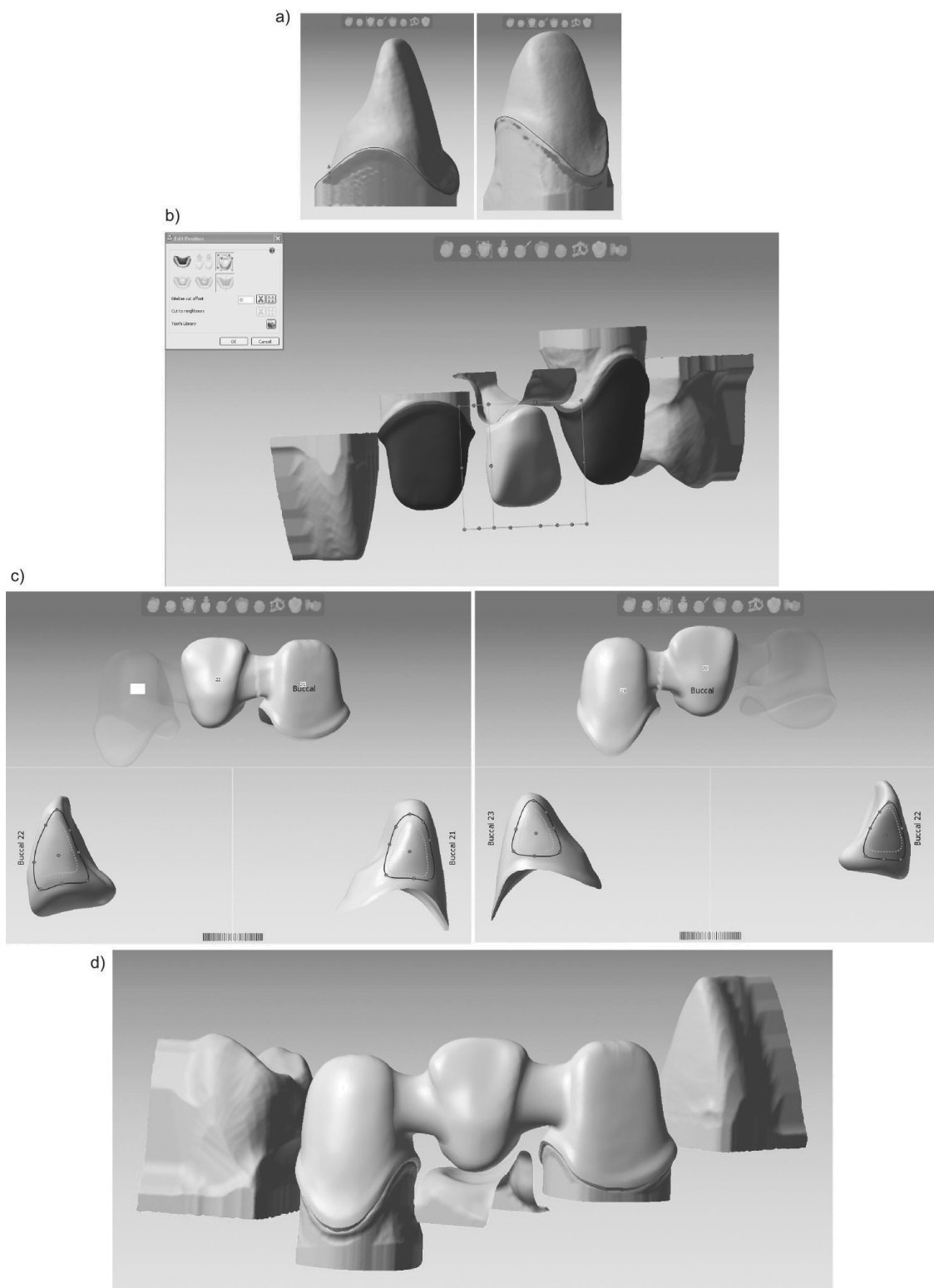
Fig. 7. Designed bridgeworks in DentCAD: a) draw of a preparation of line pillar teeth 21 and 23 at the shoulder, b) design of pontic reconstructed missing tooth 22, c) construction of the connectors between a pillar and a pontic, d) complete designed bridgework
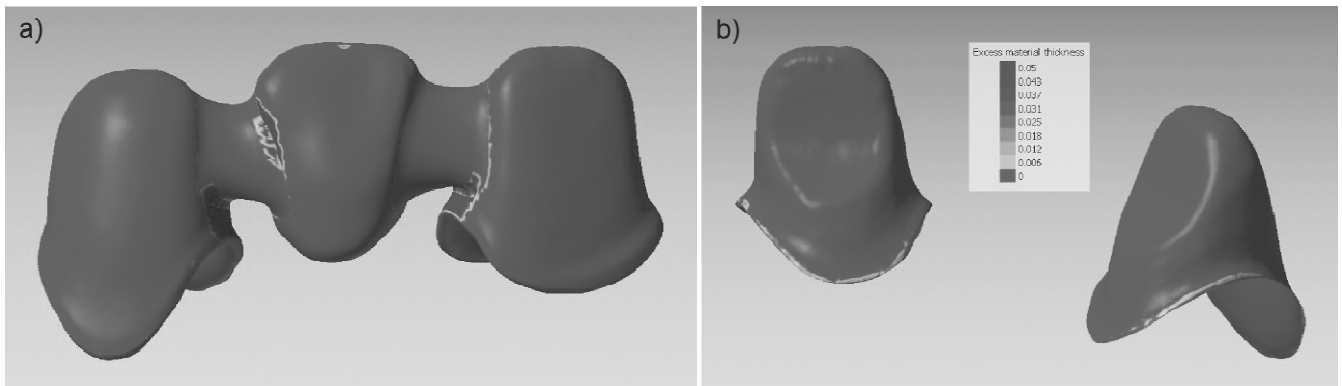
Fig. 8. Checking the surfaces compared with the milling machine possibilities: a) accessibility shading, b) tool radius shading
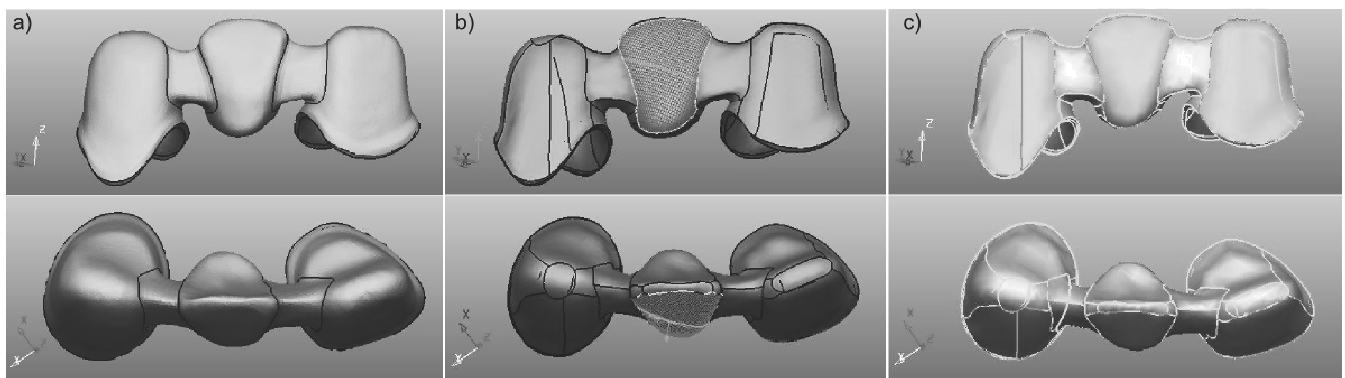

Fig. 9. Changing the stereolitographic on 3D solid: a) bridgework imported mesh from STL file, b) NURBS surfaces created on imported mesh from drawn closed loop curves, c) solid built from surfaces, with noted exemplary area
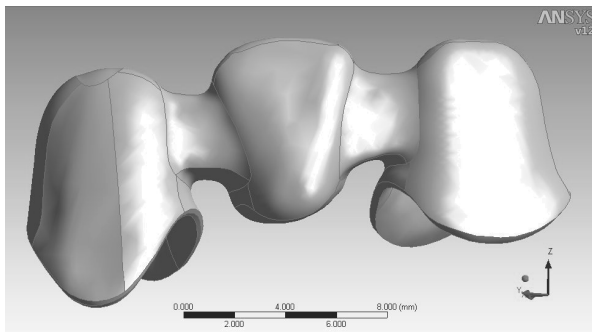

Fig. 10. Bridge model created in DentCAD, changed in CAD application on solid, imported to ANSYS software

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