Development of Rapid Prototyping CAD Models for FEM Analysis of Human Molar Tooth Crown

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Abstract— Conventionally dental crown manufacturing was done by Investment Casting only. This process goes through various steps. Each step adds error to the final part. It is very tedious for manufacturer to follow individual steps for each patient. This work presents the Rapid Prototyping as a best tool for dental prosthesis and crown manufacturing. Requirement of Rapid Prototyping system is CAD model in .Stl File Format. Two methodologies were used for CAD models development. First type of CAD model was constructed with Dental wings client software and 3S laser scanner. Dental cast model was used for scanning which was prepared for particular patient after preparation of tooth. MIMICS software was used for the development of 3D model of required tooth using CT scan images. Alternate different thicknesses crown models were prepared from MIMICS tooth model using 3-MATIC software. Both the Methodology provides CAD models in .stl file format which can be manufacture with RP system.

Key words: Rapid Prototyping, CAD, CT scan, Dental Crown, Mimics, Scanner

I. INTRODUCTION

Rapid prototyping is generally known as the 3D printing technology. It manufactures any complex shaped component provide it must have a 3D CAD model developed. This technology is mostly helpful in medical field where it is impossible to manufacture the human body implant by any means of conventional mechanical manufacturing processes. Stereolithography was the first 3D printing system introduced in 1987. Till today lots of research is done in the field of RP machine and material. Owing to its advanced techniques and materials, it can also manufacture the metallic part. 3D printers help to manufacture any complex shape component without tooling.

Dental prosthesis manufacturing industry follows the manual process for individual patient prosthesis. A 3D printer is the tool which uses biocompatible material and removes that lengthy manual process. The main requirement of this technology is the three dimensional CAD model of the part which is to be manufacture. Manufacturing of human body part implant and to develop CAD model for same CT and MRI scan is required, but for dental crown manufacturing, it is not convenient. This process becomes more critical for simple crown manufacturing. In Dentistry when maxilla or mandible was damaged at that time, 3D model is constructed with the help of CT or CB CT scan. 3D doctor and Mimics are the medical data processing softwares which use to get the CAD model of body part. Today this technology is used for manufacturing of mandible implants made from of titanium. This 3D printed model helps Doctors for dental surgery and dental implant fixation and exact positioning.

II. LITERATURE SURVEY

Baradeswaran A. et al.[3] analysed the case study in which Patient suffered from Mandible Tumour. It is very difficult to Chew, Swallow and close the mouth. It's the challenging work to the surgeon to do the surgery. For that both Engineer and Surgeon sat together and done this design. As per the surgical parameters and planned method on the designed prototype model with the help of CT scan and MIMICS software. This designed Implant done for RAGAS DENTAL COLLEGE, Chennai. Adam Chromy et al.[4] Concluded that CT scan, MRI scan, Ultrasonic etc. none of these technologies is intended to provide 3D model of patient's body surface only. All of them provides image of inner structures. Proposed Robotic 3D Scanner consists of laser scanner, which is mounted on industrial manipulator's end-point. This methodology is helpful where only surface profile is requiring not an internal structure. Eduardo Gomes Ferraz et al.[6] The 3D Doctor software was used to make virtual 3D images. At this software, during the segmentation phase, the program automatically determines the lower and upper gray-scale values. In this study, they chose to accept the lower limit of the gray scale, provided by the program and the upper limit was always the maximum of the scale. This definition was facilitated because the mandibles do not have soft tissue.

III. CAD MODEL DEVELOPMENT WITH 3D SCANNER

3D laser scanner helps to get the geometry of the existing model but the requirement is to get the missing geometry. Patient's cast model of mandible and maxilla scanned using dental wings 3S series laser scanner. The data capture was used to get the crown for particular tooth with the help of dental wings client software. Steps to get 3D CAD model as follows

A. Impression

Impression had taken with the help of dental impression tray and impression plaster. This impression is a negative or reverse, image of the tooth. It was used to prepare a diagnostic cast.

B. Cast

The next step is to prepare another type of plaster, known as model plaster which is harder than the impression plaster. Once again the plaster was mixed with the required amount of water and that poured into the impression mold to get the positive model of the tooth, known as a cast.

Fig. 1: Cast Model of Patient

C. Grinding and Finishing Cast

The unnecessary surface material of the cast model is removed using grinding and only the layout of teeth remains. After this the pins are inserted inside the hole made by using laser and that model fixed in plane base and some cuts are made by laser to make separate tooth which is required for individual scanning.

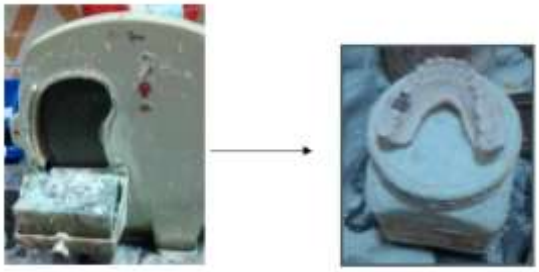

Fig. 2: Cast Model Grind & Only Layout of Tooth Remains

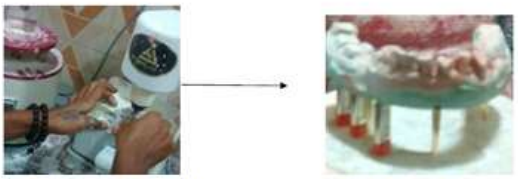

Fig. 3: Preparation for Single Scan Tooth

D. Fixing Teeth Layout on Plane Base

It is the done for the fixing of cast model to scan in scanner. Scanner has two types of fixture one for total model scanning and second for individual scanning.

Fig. 4: Cast Model Fix in Plane Base with the Help of Pins

E. Development of CAD model in Dental Wings Client Software

In this both upper and lower model is scan with 3S laser scanner, also the single tooth scan on which crown is to be developed. Software contains the geometries and surface profile of the human teeth. During scanning it is required to select tooth number from given standard model before scanning particular tooth.

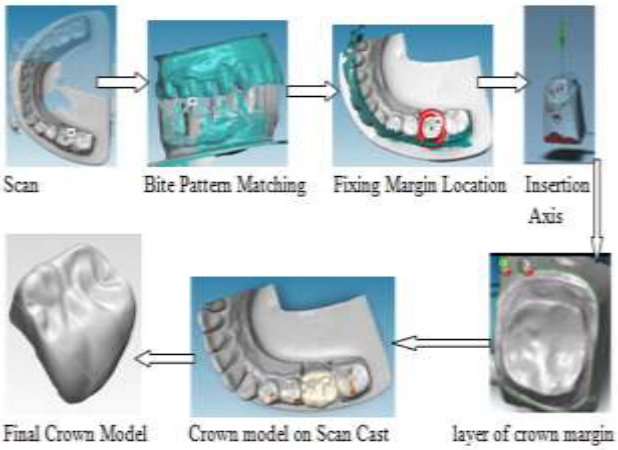

Fig. 5: Crown developed on dental wings client software interface

As shown in Figure 5 total dental cast model after selecting tooth number is scanned using 3S laser scanner. Only half portion of teeth layout is selected for the further processing which contains the prepared tooth. Reason behind to select only half portion for further processing is to avoid unnecessary processing time and memory. Some points are selected for the positioning of upper tooth profile with lower one. Shoulder and Ditching Optimization tool is used which place the Green margin line automatically. Software contain CAD tool in which final prosthesis i.e. crown model is developed and exported as .stl

IV. CAD MODEL DEVELOPMENT FROM DICOM IMAGES

A. 3D Model of Molar Tooth

DICOM images are taken with 0.8mm thickness. Number of slices for total scanning taken is 166. Five minutes are required for the total scanning process CT scan images data is imported in MIMICS software. Thresholding is used for the separation of other body tissue from required part. Automatic thresholding is used for Enamel. The thresholding value ranges from 1553 to 2850. 3D model is developed for the enamel parts. It includes all the teeth with mandible and maxilla part. Single molar tooth is separated from total 3D model of teeth by using lasso tool which separate mask in 3D. This 3D molar tooth is exported to .stl file format.

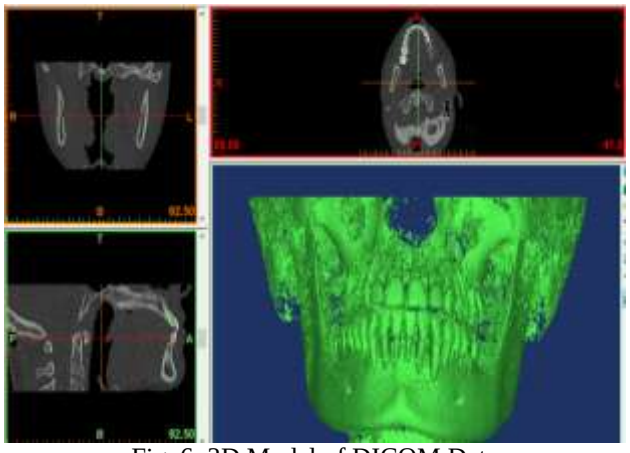

Fig. 6: 3D Model of DICOM Data

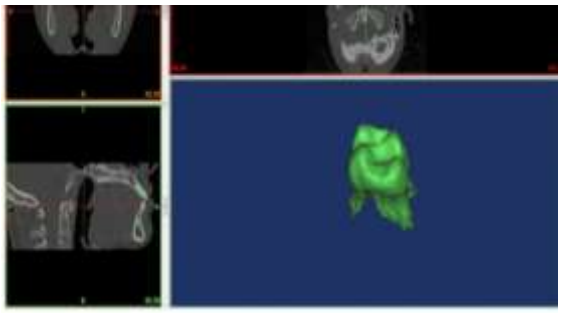

Fig. 7: Separated Single Molar Tooth

Slice Thickness	0.8 mm
No. of Slice	166
Total Length	136 mm
Current	81 mA
Voltage	120 Kv
Duration	5 min

Table 1: CT Scans Details

B. Crown Model with Different Thickness

Molar 3D model imported to 3-Matic software. Different thickness crowns are developed with Wrapping command and some Boolean operations. Figure shows the sequential procedure for the crown model development. The molar tooth model of .stl file is imported in 3-MATIC. Tooth is wrapped with required thickness. The Section plane had drowned with required height. Molar tooth is cut through the section line. Boolean operation subtraction is used for the crown model development. The crown model are developed with 1mm, 1.5mm, 1.75mm, 2mm, 2.25mm, 2.5mm.

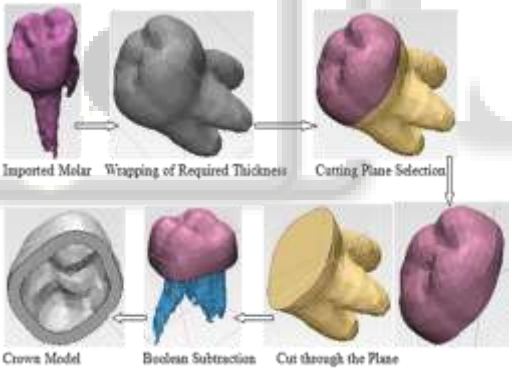

Fig. 8: Steps to get crown model in 3-matic

V. FEM MODEL PREPARATION WITH 3-MATIC SOFTWARE

The model constructed with Dental wings Client software and MIMICS both the model had triangular meshing with irregular edge length. The remesh operations enable quickly and easily transform badly shaped triangles into more equilateral triangles. The more geometrically regular triangles are the better and more reliable for the results of the FEA.

Fig. 9: Mesh Quality MIMICS Model before Remeshing

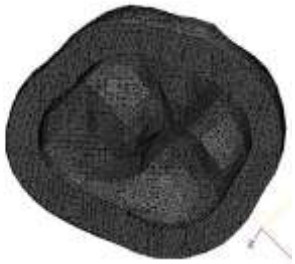

Fig. 10: Mesh Quality after Remeshing

The variation of the triangles when Remeshing and Remeshing Optimization tools were used is shown in Table II.

Crown Model	Original Triangles	Remeshing Triangles	Optimized Triangles
Dental wings	46174	7134	3606
1mm	1766	3872	3504
1.5mm	1890	4286	3862
1.75mm	2014	4532	4026
2mm	2080	4348	4183
2.25mm	2100	4912	4306
2.5mm	2186	4674	4470

Table 2: Remeshing Analysis

Volume meshing is used to convert surface meshing in to solid. A volume mesh is necessary for FEA purposes. A volume mesh can consist of tet-4 or tet-10 elements. The Create Volume Mesh operations enable to quickly create a volume mesh from a surface mesh. The more geometrically regular the triangles are of the tetrahedral the better and more reliable the results of the FEA calculations. Converted volume mesh has element type Linear Tetrahedral, its name in ANSYS APDL is Solid 185. Table shows the nodes and elements for the different models

Crown Model	Nodes	Elements
Dental Wings	2895	12623
1mm	2399	9407
1.5mm	3313	14768
1.75mm	3815	17659
2mm	4403	21013
2.25mm	4403	24313
2.5mm	5536	27864

Table 3: Nodes and Element after Volume Meshing

VI. CONCLUSION

Dental wing client is the good software for the development of RP model for the actual manufacturing of functional crown. This model cannot be use for FEM analysis because of the surface geometry and having very dense triangular meshing. Meshing of this model is not possible in ANSYS, because of surface geometry. 3-matic software is helpful to convert surface model in to solid model. Remeshing and meshing optimization tool helps to optimize meshing by converting irregular triangles into equilateral triangle. Dental wings software develops model by scanning the cast model hence thickness of crown model exactly matches with the clearance gap. This model can be directly use for manufacture with Desktop CNC milling machine with material Zirconia. Different thicknesses models were taken for the analysis of crown and various thicknesses were developed with mimics and 3-matic software of materialise.

3-matic is the best software for the preparation of model for FEM analysis. Model Developed from DICOM images only use for analysis purpose cannot be use for actual manufacturing. To manufacture crown scanning of cast model or directly scanning of tooth prepared is the best way. CT scan data is not useful for manufacturing functional crown. It can be use for surgical guide, implant design and mandible design purpose.

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