

Innovative development of the RP assisted customized surgical guides in various surgeries

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Abstract

The unique capabilities of the Computer Aided Design (CAD) and rapid prototyping (RP) have been useful for designing and manufacturing of the customized surgical guides (CSGs). In complex surgeries the CSGs have been shown to provide an accurate means of transferring virtual surgical planning (VSP) to actual surgery. The main purpose of this study is to highlight the different areas where RP assisted CSGs have been prominently use. This paper describes the successful application of RP for the production of CSGs in twelve different areas of complex surgeries. Rapid manufacturing of CSGs using RP technique and their applications; for drilling, cutting and positioning of the implant in various complex surgeries is given in this paper. Otherwise these types of complex surgeries could not be accurately treated through traditional surgeries. Different case reports are noted in this study to know the various innovative ideas related to the RP assisted CSGs. The detail methodology for development of CSGs is also described in this paper. The applications reported here have demonstrated that RP is a viable process for the manufacturing of CSGs. This approach shows good results in designing and manufacturing of the CSGs. Using advanced tools; VSP, CAD and RP for development of CSGs for the accurate surgery are possible easily. The main aim of this paper is to represent the applications of RP technology to direct manufacturing of CSGs in various complex surgeries.

Keywords: Virtual surgical planning, Computer aided design, Rapid prototyping

Introduction

The CSG is a jig designed and manufactured by an engineer with surgeon input in complex surgeries using CAD/CAM technology and RP. Designing and manufacturing of CSGs are possible according to the pre-operative VSP of the engineer and surgeon with the aim to transfer this plan into the operating theatre [Oliveira et al., (2008); Fantini et al., (2013)]. CAD/CAM and VSP has improve preoperative planning and understanding of the surgical anatomy and has facilitate the digital preparation of CSGs. It consists of intraoperative instruments that transfer the VSP to the operating field for the exact resection, drilling or accurate placement of the implant in the surgery site. This process have the potential of reducing the major negative changes in the patient's quality of life that can lead to low self confidence and negative self perception [Logan et al. (2013)]. In this paper the twelve different applications of CSGs in various complex surgeries and manufacturing methodology for the innovative development is discussed.

Methodology for development of CSGs-

Radiology

The scan data of CT, CBCT or MRI in DICOM format are generally useful for the development of the CSGs. These are the inputs to develop the CSGs.

Image processing

By using various advance image processing software like Mimics (Materialise NV, Leuven, Belgium) the collected data of CT, CBCT or MRI scan in DICOM format have to be convert into RP compatible STL format for the development of the CSGs. A thresholding technique is useful in order to highlight the areas of interest using exact threshold level for bone. A 3D model of diseased

part can quickly and easily create with the segmentation done. In the case of the diseased anatomy, reconstruction times ranged from 2 minutes for basic models where minor details were ignored, to half an hour for model where all details were included such as surface indentations. The sophisticated measurement tools in software provide accurate dimensions of complex geometries, allowing for accurate measurements and greater insight into the morphology of the diseased anatomy. The precise measurements which can be determined using software aid in the choice of the most appropriate CSGs design and surgery planning. Finally obtained 3D model of diseased anatomy have to export into STL format for the designing of CSGs.

Virtual surgical planning

The advance tools in software has capable to eliminate the inaccuracies commonly associated with traditional surgery planning and simplify the execution by eliminating surgical steps such as intraoperative measurement, marking of implant positioning site, etc. [Polley and Figueroa (2013)]. The computerized plan can be easily transfer accurately to the surgical site to position the implant, taking cut or drilling at the time of surgery using VSP [Hsu et al. (2013)]. Before design the CSGs the VSP plays vital role to achieve the accuracy in proper fitting of the implant, drilling or cutting on accurate site. VSP decides the size of implant, thickness of implant, screw positioning of implant, shape of implant, exact match of the implant, also it plan for design of CSGs as per the need like drilling, cutting or positioning of the implant. The main advantage of VSP compared with conventional planning is that it significantly reduces the laborious manual steps [Schepers et al. (2012)].

CAD of CSG

Based on 3D model of the affected anatomy the optimal CSGs design generally plan. Surgery simulation on the 3D CAD model of affected anatomy makes it possible to begin designing CSGs in currently available advance CAD software like 3Matics. To create these CSGs, the bone surface was inversed which assured of a perfect fit. From a surgical point of view, the CSGs facilitates the identification of the most appropriate site with regard to bone volume, blood supply, and precisely assists in resection of the desired bony segment in a correct angle at the recipient site [Dérاند et al. (2012)]. The wrap tool is used to design the CSGs for the accurate transfer of contour of affected anatomy on the guide. The designing procedure of the CSGs is given in “Table 1”.

Table 1. Design methodology

S.N.	Design methodology
1	Radiology
2	Image processing
3	Virtual surgical planning
4	CAD
5	Export into RP compatible STL format

Manufacturing of CSGs

After completion of the design of the CSGs, it has to save in STL i.e. RP compatible format for manufacturing. Various authors used various RP techniques for the fabrication of the CSGs. Among them FDM, SLA, SLS, 3DP are the common RP techniques use to easily manufacture the CSGs in plastic material. As per requirement DMLS, SLM, EBM are some RP techniques are used by different researchers to fabricate CSGs in metallic form.

Even though the virtual model shows that there is a perfect fit, the researchers will have to play it safe, for that mock test of fitting and cutting with their own hands is important. In order to do so

prior to a real surgery, the RP plays dominant role to produce the diseased model and corresponding CSGs. If surgeon satisfied with the mock test the CSG can use in the surgery after sterilization. The manufacturing procedure of the CSGs is given in “Table 2”.

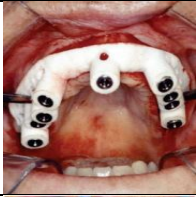
Table 2. Methodology for the manufacturing of the CSGs

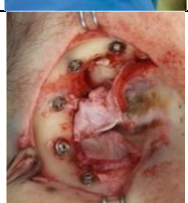
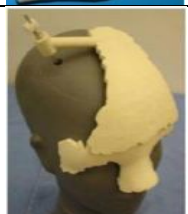
S.N.	Manufacturing process steps
1	Slice STL file using RP software and link with RP machine
2	Fabrication of CSG using RP machine
3	Post processing for finishing
4	Try in before surgery on RP assisted diseased model

Applications of RP assisted CSG for various surgeries

Author noted the twelve different areas where the RP assisted CSGs are prominently use in the complex surgeries. Among them dentistry and craniomaxillofacial (CMF) are the common fields where CSGs have been used tremendously. The various application of the RP assisted CSGs in various surgeries are given in the “Table 3”.

Table 3. Application of RP assisted CSG for various surgeries

S.N	Area	Application	RP assisted CSG	Researchers
1	Dentistry	CSG for drilling- Drilling and placement of the implant at exact position and orientation		Giacomo et al. 2014
2	CMF	CSG for resection- Accurate resection of the bone tumor		St-Hilaire et al. 2012
3	PSI	CSG for drilling- Accurate insertion of the screws in the pedicles		Porada et al.
4	THA	CSG for resection- Accurate resection of the femur head		Drstvensek et al. 2013

5	TKN	CSG for resection- Accurate resection of the knee		Bagaria et al. 2011
6	CO	CSG for resection- Accurate resection and placement of the plate		Dobbe et al. 2013
7	BRAR	CSG for resection- Accurate bone resection and allograft reconstruction		Bellanova et al. 2013
8	OO	CSG for resection- Exact cutting of the cancer affected part		Khan et al. 2013
9	MTPJ	CSG for drilling- Exact placement of k wires for twisting		Hirao et al. 2014
10	OIP	CSG for drilling- Placement of implants at accurate location in the orbit		Unknown author
11	TMJ	CSG for resection- Exact resection and positioning of the scaffold		Ciocca et al. 2009
12	NS	CSG for drilling- Used in the deep brain stimulation		Rajon et al. 2006

CMF- craniomaxillofacial, PSI- pedicle screw insertion, THA- total hip arthroplasty, TKR- total knee replacement, CO- corrective osteotomy, BRAR- bone resection and allograft reconstruction, OO- orthopedic oncology, MTPJ- metatarsophalangeal joint surgery, OIP- orbital implant placement, TMJ- temporomandibular joint surgery, and NS- neurosurgery

Discussion

In this paper the development of the RP assisted CSGs and their applications in twelve different areas of medical in complex surgeries have reported. According to the researchers, it is really very

easy to find the best fit for positioning the CSGs manually, because of no significant free motion while the placement in position with slightly pressing against the affected bone. Although the technique requires a very clean preparation of the bone surface, including removal of the attached muscle and fat tissue, it will still prove to be better than other techniques reported in the literature. There are in fact several distinct advantages of using advance software to design the CSGs. The surgeon can decide on the location, orientation, and size of the customized implant based on the unique morphology of the patient prior to the surgery. Also it helps to take proper cut, drill holes in the complex sites in the surgery. This technique is very simple to use, so it does not require a specific expertise on the surgeon's part. It eliminates the need for complex equipment and time consuming procedures in the operation theatre, thereby reducing the operation time considerably. Screws for fixation implant can be accurately place without perforating the nerves. The need for fluoroscopy during implant placement and screw insertion is eliminated, which considerably reduces the radiation exposure to the patient and the members of the surgical team [Lu et al. (2012); Cansiz et al. (2013)]. This is important as surgeons these days are tackling more challenging anatomy than ever so the valuable information provided by the 3D reconstructions ensures that the surgeons don't encounter any unforeseen problems during surgery; this in turn increases confidence in the procedure. Using this technique the 3D reconstruction and manufacturing of CSGs is quick to perform and also aid surgeons in improving the treatment. With CSG's wide applicability, high accuracy, proven safety and cost-effectiveness, RP assisted CSGs will likely enjoy widespread use in the future in various complex surgeries.

Conclusions

This study shows that RP is a viable rapid manufacturing method for the direct production of CSGs for various complex surgeries. The time and cost for development of CSGs using RP is comparable to other manufacturing processes. The CSGs produced using the RP process have been shown to be acceptable in terms of accuracy, quality of fit and function to surgical guides in twelve different prominent surgical areas which could not be otherwise possible easily using traditional manufacturing methods.

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