

Chapter 16. Integration of Medical Imaging and Rapid Manufacturing

Rapid Manufacturing in Clinical Practice?

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During the last few years, the combination of medical image processing and rapid manufacturing techniques has proven to be a very important development.

Medical Rapid Prototyping is the latest technique, which allows us to build physical copies of a patient's anatomy directly from images of a hospital scanner. The use of such anatomical models can generally be divided in three areas:

1. Medical models as "concept models". These models provide a clear picture of a clinical situation and give the surgical team 3D spatial tactile information.
2. In complex surgery, medical models are used to simulate an intervention. Cutting, drilling and re-positioning of parts for complex surgery can be practised on the model.
3. Depending on the application, medical models can serve directly as a master or indirectly as a negative for casting a customised implant.

Medical models have been demonstrated to facilitate understanding and awareness of medical problems, contribute to faster intervention, reduce operation time, minimise patient discomfort, improve treatment success rate, increase the speed of recovery and limit costs. Medical Rapid Prototyping has been proved to provide significant benefits for various pathologies in a number of medical areas.

Medical Imaging and Rapid Prototyping (RP)

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The combination of Medical Imaging and Rapid Prototyping is a fast-expanding field with a large application potential in medicine and related fields. Typical applications include the making of three-dimensional copies of anatomical structures, the production of individually designed prosthesis models (link between Medical Imaging and Computer Aided Design and Finite Element Analysis) and the replication of anatomical objects for educational purposes.

This presentation provides an overview of available technology and methods for the development of anatomical rapid prototyping models, as well as potential applications.

Anatomical RP Models in Maxillofacial Surgery

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This presentation describes the use of anatomical physical models for maxillofacial surgery, where routine CT imaging was unable to provide an answer to the clinical case. A computer and manufacturing assisted diagnostic method was pursued which involved image processing of CT data, three-dimensional reconstruction and development of an anatomical model through rapid prototyping techniques.

The developed rapid prototyping model depicted accurately the geometrical characteristics of healthy

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and pathological tissues with the problematic area selectively coloured. The image processing and subsequent three-dimensional and physical modelling demonstrated the patient's condition and the overall method helped the surgical team to reach a diagnosis and decide the potential surgical intervention avoiding unnecessary patient discomfort and risk. The communication of the pathology among the medical team, as well as between the surgeon and the patient was greatly facilitated. The application of computer and manufacturing methods in the diagnosis and treatment of complex maxillo-facial cases can sometimes be decisive for the success of the clinical result.

Computer-Assisted Reconstruction of the Midface

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The recent developments in 3D CT enhancement software with the use of MIMICS and Surgicase Pro are utilised within Morriston Hospital for the planning and treatment of oro-facial cancer patients. Such applications will be illustrated in this talk with rhinectomy and nasal reconstruction patients.

In general, the way that Morriston Hospital has managed to use these software programmes to enhance the quality of life, reconstruction and treatment of these patients will be presented.

Computer-assisted reconstruction methods have also been shown to reduce the intra-operative treatment/surgery time for these patients as the treatment plan for the accurate placement of implants for reconstruction and tumour resection margins is defined prior to surgery. In addition, the workload of the technicians within the unit has now been reduced

by using commercially available stents as drill guides for placement of oro-facial implants.

Custom-Designed Craniofacial Implants

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This presentation will demonstrate how advanced software and hardware can be used to combine prosthetists' traditional handcrafting skills with the advantages of computer aided design and manufacturing techniques. This has become possible by the combination of free form digital representation of shape and unconstrained tactile feedback control which provides the quantum leap in CAD that allows hand skills to be directly applied to computer aided design and subsequent manufacture of complex anatomically shaped implants and prostheses.

Computer-Guided and Model-Based Dental Implantology

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Materialise's Medical Division has developed SurgiCase software to read in computed tomography (CT) dental scans and produce interactive 3D computer models of the bony tissue, in addition to the reformatted cross-sectional and panoramic views traditionally used for dental implant planning.

Using such software tools, the dentist can now place "virtual" implants on the computer, making use of the interactive 3D model to get the angulation and positioning just right. Moreover, an exact physical replica can be produced from the virtual 3D using

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stereolithography, one of several rapid prototyping techniques used to fabricate physical models automatically from computer data.

Because the 3D co-ordinates of the virtually-placed implants are accurately known, a drill guide, known as "SurgiGuide", can be produced to fit precisely onto the patient's bone crest, with cylinders that guide the drill to the exact position and orientation of the planned implants. The dentist simply drills through these cylinders measuring only the required depth.

SurgiGuides are usually seated directly on the patient's bone for best stability, requiring a flap to be lifted at the time of surgery. However, a mucosa supported version, suitable for fully edentulous patients, has just completed clinical trials.

The same technology is currently used to produce life-size models of the mandible, maxillofacial region, or the entire skull, which are invaluable for planning reconstructive surgery.

Clinical Experience with RP Dental Drilling Guides

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In order to produce an acceptable cosmetic outcome, it is critical that dental implants are placed in positions, which correspond exactly to the teeth in the final restoration. They must closely follow the crown to root structure of a natural tooth.

To achieve this goal, a radiographic stent is made as a copy of the predetermined positions of the teeth in the final bridge. By introducing Barium Sulphate into the acrylic mix of the stent an outline of the teeth in the required position will be seen on the formatted images from the CT scan.

Using 3D computer software the images can be manipulated allowing the operator to virtually place

dental implants in the optimum positions in the available bone whilst still lining up with the teeth in the radiographic stent.

This information is stored and used to manufacture an RP drill guide. This ensures the precise placement and angulation of the drill preparing the site for placement of the implants in the predetermined position.

At the restoration phase the implants are used to support crowns or bridges. As they are directly in line with the predetermined tooth positions they closely resemble the appearance of natural teeth.

Clinical Validation of Placement of Zygoma Implants using Stereolithographic Drill Guides

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In this study, the precision of placement of zygoma and standard implants in patients with severe maxillary atrophy, using stereolithographic drill guides was evaluated.

Patients were treated with a combination of standard implants anteriorly and zygoma implants in the posterior maxilla. The validation was done by comparing the actual position of the placed implants as seen on the postoperative CT scan to the preoperative treatment plan. We calculated deviations in entry point, exit point and angulation of the placed implant compared to the preoperative plan.

12 of out 33 treated patients were randomly chosen for the validation study. The validation yielded following results: for zygoma implants entry point deviation was 2,8mm (sd 1.61), exit point 4.5mm (sd 3.16) and angulation 5.1° (sd 2.59); for standard

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implants entry point deviation was 1.5mm (sd 1.07), exit point 3.0mm (sd 1.74) and angle 10.5° (sd 5.94). Our system has the potential to make optimal use of CT scan images for implant treatment planning and provide a reliable transfer of that planning to the patient, minimizing risk of lesion of critical anatomical structures and avoiding need for sinus floor reconstruction in patients with severe maxillary atrophy.

Virtual and Physical Modelling of the Human Anatomy: Potential Applications

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Integrating medical imaging with traditional mechanical and manufacturing methods has shown an important potential presenting a number of benefits for patients and clinical staff. In particular, by integrating the areas of Medical Imaging, Computer Aided Design, Numerical Analysis and Rapid Manufacturing within a hospital environment, it is possible to obtain geometric information of body structures and practically generate accurate three-dimensional virtual or physical models of anatomical parts.

Such models can then be processed as necessary for visualisation, physical modelling or analysis purposes and applied for diagnosis and preoperative planning of complex pathologies, design and verification of implants or even educational purposes. For example, a virtual or solid model of a patient's anatomy would offer many advantages for surgeons planning complex operations. A model can improve the communication of diagnosis within the medical team and between doctor and patient. In addition a model

provides a facility for rehearsing a difficult operation. Bone grafts can be planned, created, orientated and positioned before entering the operating theatre. Custom-made templates can be designed in order to transfer the operative plan from the model to the patient. Solid models of a specific structure can also allow the design of custom-made implants, ensuring a good fit, correct function and in general improving the implants' lifetime and effectiveness, and reducing the potential risk to the patient.

Overall, an integrated imaging and engineering approach can be used within a hospital environment to introduce new ways of visualising and using medical scanner data.

Open Discussion: How can we introduce medical modelling into a clinical environment?

The workshop, apart of presenting current model development procedures and medical applications, intends to bring together ideas and knowledge from various clinical areas and to discuss the possibility of introducing a model-making system into a clinical setting.

The workshop is organised by the Biomedical Modelling Unit, University of Sussex (www.sussex.ac.uk/Units/biomodel) and is sponsored by Materialise N.V., Belgium (www.materialise.com) and Image Diagnostic Technology (IDT), London (www.ctscan.co.uk).