3D Printing in Healthcare: from Concept to Clinical Practice

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Up and Coming Techniques in Medical Physics
Translated into Clinical Practice

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3D Printing

What will be covered

• What is subtractive and additive manufacturing?
• Problems faced in the NHS
• Potential impact within NHS
• 3D printing process
• 3D printing technology
• Individual printers vs Hub facility vs External Service
• Applications in Healthcare
• Research & Future applications
• Conclusions
## What is Subtractive and Additive Manufacturing?

**Subtractive manufacturing**
- Performed using CNC machines
- Works by removing material
- Can work from large range of materials
- Cannot do hollow or very complex objects.

**Additive manufacturing**
- Can be performed by 3D printers
- Works by building up an object layer by layer
- Has a limited range of materials
- Some printers can produce an object manufactured in multiple materials.
- Can produce complex and hollow objects.

## Problems being faced in NHS

**MONEY!!!**
- How can you get funding?
- How can you use and prove that 3D printing will enhance your clinical practice?
- Do you use external or internal 3D printing facilities. Is it cost effective?

**E-Health or IT**
- It’s a printer!!!!!

**Healthcare Science**
- Recruitment of skilled mechanical engineers. Is it a dying art?
- Changes in legislation regarding in-house manufacture.
- What is a Medical Device?
- Where does 3D printing sit?
- How can we manufacture items within MDD?
Potential Impact of 3D Printing in Healthcare

- Improved efficiency of patient pathway
- Cost savings
- Improved accuracy and safety of procedures and service delivery.
- Achieved by
  - Reducing theatre time
  - Reducing need for repeat procedures
  - Customising solutions to patient’s needs
  - Patients are better informed

Where are we going?

CT

3D printed objects

Surface & Volume Rendering

(DICOM dataset used for the CT image and surface render were obtained from Osirix website sample datasets. http://www.osirix-viewer.com/datasets/)
3D Printing Process

Data Source
- Tomographic Imaging Modality
- CAD / CAM
- 3D Scanner

3D Reconstruction and Modelling
- 3D Modelling, Manipulation of Data & Procedure Planning

3D Printing
- 3D Model Printing, Preparation & Printing

Model Completion
- Finished product

3D printer choice?
Consider the following when choosing the printer and technology

- **Available budget?**
- **Size of objects to be printed?**
- **For the finished product**
  - What will it be used for?
  - Where will it be used?
    - Require sterilisation, strength, flexibility ........?
  - What type of material and will it require multiple materials?
    - Rigid, flexible, biocompatible, metallic, polymers, wax ceramic etc.
  - Does the model require to be completely solid, honeycomb build, or hollow?
### Individual printers vs Hub facility vs External Service

<table>
<thead>
<tr>
<th></th>
<th>Individual Printer</th>
<th>Internal Hub</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Setup Cost</strong></td>
<td>Low (printer cost)</td>
<td>High (but could be used for income generation to other NHS boards)</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Printer quality</strong></td>
<td>Low</td>
<td>Better / Best</td>
<td>Best</td>
</tr>
<tr>
<td><strong>Model Expense</strong></td>
<td>Low (Cost of materials)</td>
<td>Low to Mid (Cost of materials + ? proportion of staff)</td>
<td>High (3 to 15 times cost of materials)</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Low (only used by one service)</td>
<td>High (used by multiple services, multiple print jobs &amp; easy prioritisation)</td>
<td>High (multiple paying users, multiple print jobs possible &amp; prioritisation at a price)</td>
</tr>
<tr>
<td><strong>Idle time</strong></td>
<td>Mid to High (depending on internal demand)</td>
<td>Low (used by multiple services, &amp; possible external parties)</td>
<td>N/A (multiple paying users)</td>
</tr>
<tr>
<td><strong>Wastage</strong></td>
<td>Low to Mid (Can see wasted materials if bought in bulk)</td>
<td>Low</td>
<td>N/A (Can incur additional cost for changing materials)</td>
</tr>
<tr>
<td><strong>Skill &amp; Knowledge</strong></td>
<td>Mid</td>
<td>High (Specialised)</td>
<td>High (General)</td>
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### 3D Application within Healthcare

- Pre-Surgical planning.
  - Pre-assessment of trauma.
  - 3D modelling of procedure and printing of bone graft templates.
  - Reconstructive surgery cutting guides.
  - Customisation and forming of implants on prints.

- Physician to physician communication.
  - especially in Multi Disciplinary Team environment

- Physician to patient procedure explanation.

- Medical student / junior doctor education.
Maxillofacial surgery

- Currently used extensively by Maxillofacial surgery in NHS Lothian for:
  - Surgical planning
  - Implant pre-contouring
- The printing is done outside of NHS Lothian because there is no internal facility.
- Has a significant cost per year
- Time aspect
  - Complete procedure rehearsal can require multiple prints of different sections of procedure as plan develops.
  - External printing turn around time up to 2 weeks.
  - Short notice rescheduling of theatre time for cancer patients.
- Patient's face rebuilt with 3D printed parts (Cardiff)
  - [http://www.bbc.co.uk/news/health-26543569](http://www.bbc.co.uk/news/health-26543569)

Orthopaedic Surgery

- Procedure planning and rehearsal.
  - Joint replacement etc.
  - Corrective surgery
- Cutting guides
- Patient specific braces and splints
- Inverness girl Hayley Fraser gets 3D-printed hand (Inverness)
Plastic Surgery

• 3D printed anatomy templates
  – Procedure planning,
  – Bone and soft tissue reconstruction guides.
• 3D printing of scaffolding for stem cell seeding and implantation.

• 3D printing helps give girl a new face

Cardiology & Cardiac surgery

• Used in adult and paediatric cases
• Pre-surgical planning examples
  – Tumour resection
  – Valve repair / replacement
  – Congenital diseases
• Patient procedure explanation
• Cross hospital case consultation
  – Services split over country

• 3D printed heart helps to save girl’s life
  – http://www.bbc.co.uk/news/health-30996500
• 3D printing makes heart surgery safer for children
  – http://www.sciencedaily.com/releases/2015/01/150129093946.htm
• 3D-printed model heart helps doctors save a little girl’s life
Neurosurgery

- Pre-Surgical planning of procedures makes the actual procedure quicker, safer and less invasive.
  - Tumour resection
  - Aneurysm surgery
  - Complex surgery

- 3D Printing Makes a Complex Brain Surgery Possible, Saving The Life of a 50-year-old Woman in China

- Surgeons use 3-D printer to prepare for surgery

Healthcare Sciences

- Radiotherapy – Bolus, phantoms etc.
- Imaging – QA and anthropomorphic phantoms, positioning rigs etc.
- Rehabilitation Engineering & Assistive Technology – customised solutions for patients etc.
- Medical Equipment – medical device customisation.
- Clinical Engineering – medical device prototyping.
- R&D – various academic and clinical research applications.
Radiotherapy example #1

- Custom bolus printing
- 3D printed bolus or surrogate surface render
  - help improve accuracy in bolus reconstruction and placement from virtual planning
- Difficult to mould around ears, nose etc
- Used for dose build-up
- Manufactured by hand using wax, gel sheets or thermoplastic

Radiotherapy example #2

- Custom phantom printing
- 3D printed phantoms for
  - Dose verification
  - Image registration
  - Machine QA
Rehabilitation Engineering and Assistive Technology

• Component manufacture for
  – custom medical equipment design
  – individual patient final use
  – custom R&D equipment design and development
  – design prototyping

• 3D Printed Assistive Technology Creation in the Clinic: A Case Study

Medical Physics Examples

• Development of custom test objects for imaging and radiation dosimetry for existing and new modalities.

Test object from 3D printed patient anatomy
3D printing of custom test phantoms

- Problems faced:
  - Simple uniform test objects have limited use in optimising modern image reconstruction algorithms.
  - Anthropomorphic test objects cost between £5k - £15k,
    - Has limited adaptation to different pathologies / imaging scenarios
- 3D printing can produce test objects adapted to specific imaging tasks and clinical indications.
  - Optimise balance between radiation dose and image quality for all patients
  - Significant cost savings.

Medical Physics Examples

- Rapid prototyping *
  - Application of 3D printing techniques in the development of prototypes decreases the time to production and improves the quality of the final product.

- Manufacturing of in-house medical devices and components. *

- Modification and customisation of medical devices.*

* All manufactured to comply with the relevant standards (Medical Device Directive etc.)
3D Research in Lothian

- Medical Imaging characteristics of 3D printed materials measured on a clinical x-ray and CT set.

- Feasibility of using 3D printed models, from 3D optical scans, during surgical reconstruction within NHS.

- Watch this space

Future applications

- Bio-printing of organs / human bodies?

- 3D printing of patient specific drugs.

- New materials for implantation or tissue equivalency.
Conclusions – 3D Printing

• A significant step forward for healthcare with huge benefits to our practice and patients.
• Not widely adopted within NHS due to money?
• Has potential to save NHS lots of money, but how to prove it?
• Only maverick groups have adopted the technology as part of their clinical practice (e.g. Maxillofacial).
• Should be made part of the patient pathway to ensure patients get the best and safest possible treatment.
• For organisations and institutes to recognise the benefits and aid in supporting adoption of & training within this emerging healthcare discipline (RCS, RCR, IPEM, IOP, IET etc.).
  – Potential for creating a network of users and providers within healthcare

References

• Inverness girl Hayley Fraser gets 3D-printed hand (Inverness)
  – http://www.bbc.co.uk/news/uk-scotland-highlands-islands-29441115
• 3D printed heart helps to save girl’s life
  – http://www.bbc.co.uk/news/health-30996506
• 3D printing makes heart surgery safer for children
  – http://www.sciencedaily.com/releases/2015/01/150129093946.htm
• Patient’s face rebuilt with 3D printed parts (Cardiff)
  – http://www.bbc.co.uk/news/health-26543569
• Good Samaritan teenager was left for dead with battered face and multiple fractures after he was beaten by a man he had stopped to help (Edinburgh)
• 3D printing helps give girl a new face
• 3D-printed model heart helps doctors save a little girl’s life