3D Printing in Healthcare: from Concept to Clinical Practice

Dr Scott Inglis
Medical Physics
NHS Lothian
scottinglis@nhs.net

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.

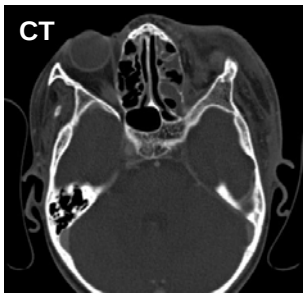
Problems being faced in NHS

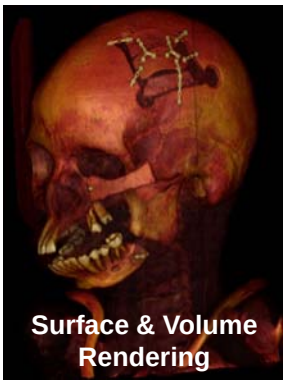
- **MONEY!!!**
  - How can you get funding?
  - How can you use and prove that 3D printing will enhance you clinical practice?
  - Do you use external or internal 3D printing facilities. Is it cost effective?
- **E-Health or IT**
  - It's a printer!!!!!
- **Healthcare Science**
  - Recruitment of skilled 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?

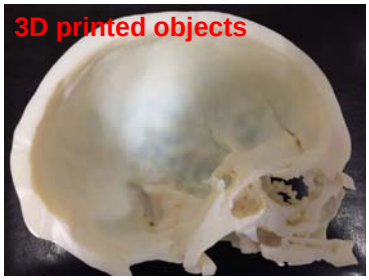
Potential Impact of 3D Printing in Healthcare

- 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?

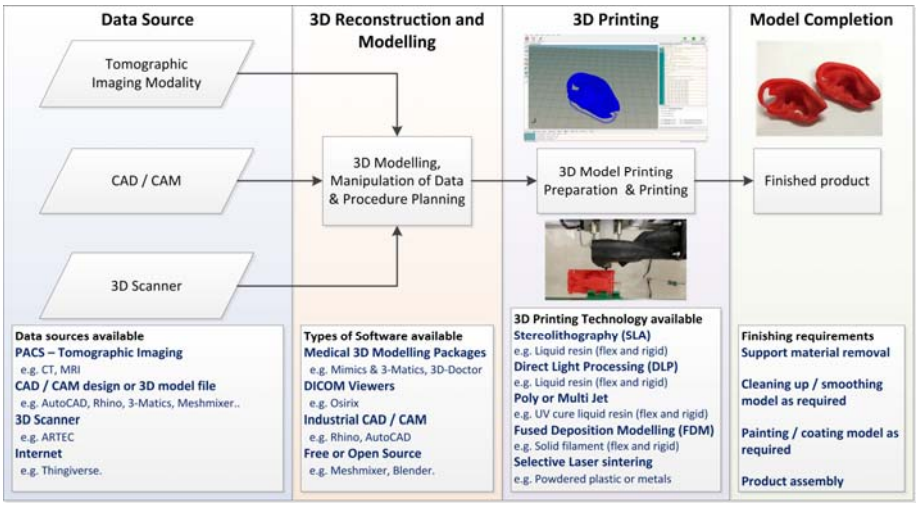






(DICOM dataset used for the CT image and surface render were obtained from Osirix website sample datasets. http://www.osirix-viewer.com/datasets/)

3D Printing Process



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, honey comb build, or hollow?

Individual printers vs Hub facility vs External Service

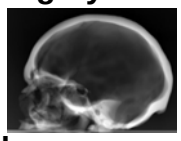
	Individual Printer	Internal Hub	External
Setup Cost	**Low** (printer cost)	**High** (but could be used for income generation to other NHS boards)	**N/A**
Printer quality	**Low**	**Better / Best**	**Best**
Model Expense	**Low** (Cost of materials)	**Low to Mid** (Cost of materials + ? proportion of staff)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

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

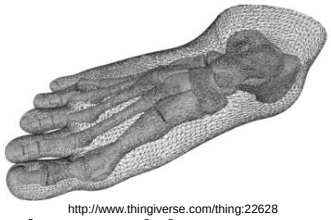
- **Currently used extensively by Maxillofacial surgery in NHS Lothian for:**
  - Surgical planning
  - Implant pre-contouring



- **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

Orthopaedic Surgery

- Procedure planning and rehearsal.
  - Joint replacement etc.
  - Corrective surgery



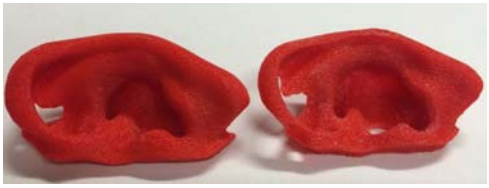
http://www.thingiverse.com/thing:22628

- Cutting guides
- Patient specific braces and splints
- **Inverness girl Hayley Fraser gets 3D-printed hand (Inverness)**
  - http://www.bbc.co.uk/news/uk-scotland-highlands-islands-29441115

Plastic Surgery

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

Surface ear print Cartilage print



- **3D printing helps give girl a new face**
  - http://www.cbc.ca/news/health/3d-printing-helps-give-girl-a-new-face-1.3014957

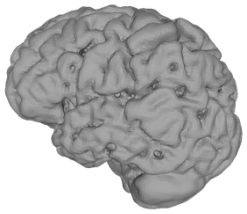
Cardiology & Cardiac surgery

- 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-30996506
- **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**
  - http://www.cnet.com/uk/news/doctors-3d-print-a-model-heart-to-help-save-a-little-girls-life/

Neurosurgery

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



http://www.thingiverse.com/thing:14352

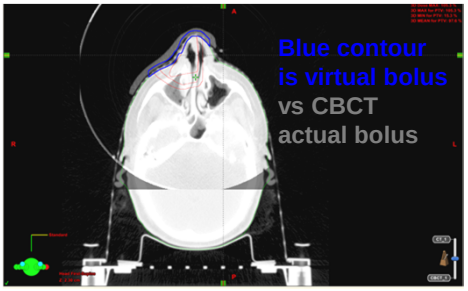
- **3D Printing Makes a Complex Brain Surgery Possible, Saving The Life of a 50-year-old Woman in China**
  - http://3dprint.com/92445/3d-printed-brain-surgery/
- **Surgeons use 3-D printer to prepare for surgery**
  - http://www.kctv5.com/story/28028513/surgeons-use-3d-printer-to-prepare-for-surgery

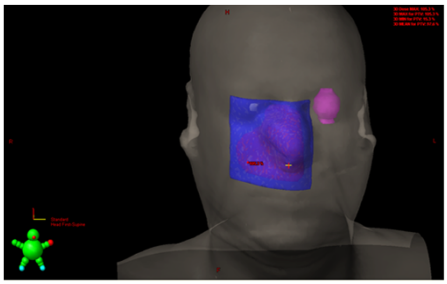
Healthcare Sciences

- **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

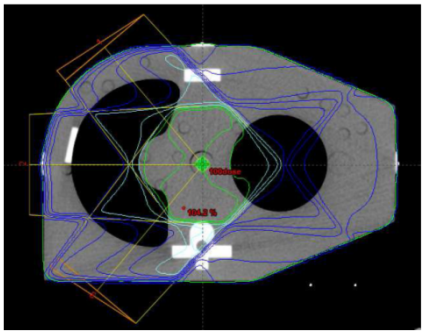


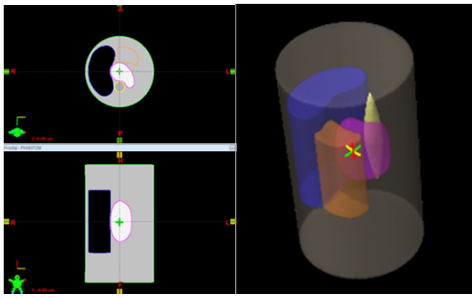


- Difficult to mould around ears, nose etc
- Used for dose build-up
- Manufactured by hand using wax, gel sheets or thermoplastic

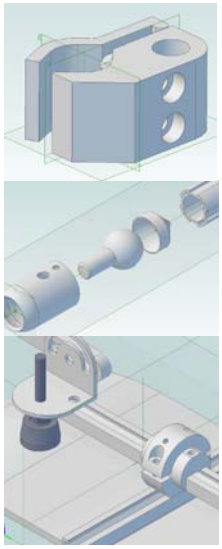
Radiotherapy example #2

- Custom phantom printing
- 3D printed phantoms for
  - Dose verification
  - Image registration
  - Machine QA





Rehabilitation Engineering and Assistive Technology

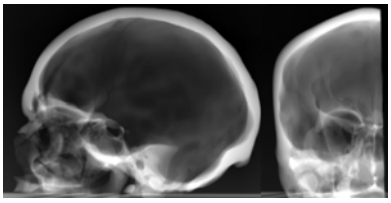


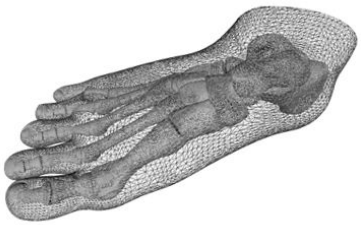
- Component manufacture for
  - custom medical equipment design
  - individual patient final use
  - custom R&D equipment design and development
  - design prototyping
- 3D Printed Assistive Technology Creation in the Clinic: A Case Study
  - http://www.resna.org/news-events/annual-meeting/workshop-descriptions/3d-printed-assistive-technology-creation-clinic

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

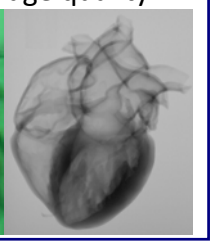




3D printing of custom test phantoms

- 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)**
  - http://www.dailymail.co.uk/news/article-2942717/Good-Samaritan-teenager-left-dead-battered-face-multiple-fractures-beaten-man-stopped-help.html#ixzz3WiQL9nxt
- **3D printing helps give girl a new face**
  - http://www.cbc.ca/news/health/3d-printing-helps-give-girl-a-new-face-1.3014957
- **3D-printed model heart helps doctors save a little girl's life**
  - http://www.cnet.com/uk/news/doctors-3d-print-a-model-heart-to-help-save-a-little-girls-life/