Università degli studi di Pavia
Dipartimento di Ingegneria Civile e Architettura
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3D Printed Tracheal Stents: overview and open challenges

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http://www-2.unipv.it/compmech/proto-lab.html

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Goals

- Custom tracheal stents accessibility
- 3D printed stents building process
- Model printing process
- Advantages and Drawbacks of customized stents
Clinical Background

- **Trachea** is a sort of pipe made of *cartilage*, usually 10/15 centimeters long.

- It connects upper airways (*Larynx, Mouth*) with *lungs*.

- Cartilaginous *ring* structure (open on the back).

- *Cilia* that keep the organ clean along with *mucus*.
The most important reason for tracheal stent implantation is **Stenosis**: an abnormal **obstruction** leading to severe **dispnea** (often misinterpreted as **asthma**) (Lorenz et al., 2003)
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**Healthy Trachea**

**Trachea with Stenosis**

Which are the treatments for stenosis?
There are a few types of surgical intervention to treat tracheal stenosis:

- **Dilation**
  - Temporary Effect
  - Possible relapse as standalone procedure

- **Resection**
  - Re-anastomosis
  - Reconstruction of the damaged area

- **Stenting**
  - Airway Support
  - Adaptable

Often these methods are combined (Brichet et al., 1999)
There are a few types of surgical intervention to treat tracheal stenosis. Often these methods are combined. The challenge is to build something that can be adaptable and printable.
There are two principal families of stent: the **polymeric** one and the **metallic** one. Both have *advantages* and *disadvantages*. (Walser et al., 2005)

### Polymeric
- Possibility of bioabsorption
- Easier to remove
- Resistant to granulation or stenosis growth
- Migration
- Difficult installation
- Mucus residue around the stent

### Metallic
- Can be released through small sheats
- Less prone to migration
- Guarantee mucociliary clearance
- Granulation tissue build-up
- Very difficult removal in certain case of incorporation
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Polymeric stents are the most useful for 3D tracheal manufacturing: **elastic**, **ductile**, **adaptability-prone**. **Engineering** and **Customization** reduce the impact of polymeric stents **cons**
Rapid Prototyping Technology Nowadays

- **RPT** (3D-printing) is becoming common place worldwide in *healthcare*

- **Printers** *high-availability*: both *commercial* and *open-source* (Tam et al., 2013)

Often, clinic management decide whether

Unfortunately, it is likely that **small communities** clinics *can’t sustain* the printer’s cost and its *derivates* (*materials, time, energy*)
3D prototyping in clinics can consist in a few categories (Tam et al., 2013)

- **Pure Stent Printing** for cure and treatment
- **Surgical Planning** / Interventional **Simulation**
- **Doctor-Patient** Education and Understanding
Why do we care studying *Customizable Stents*?

- Avenue for many forms of **treatment**
- **Reduction** of causes leading to patient noncompliance
- **Process** with **multiple factors**
- **Resources** and **studies**; still expensive, even if every day more demanded

We must analyze each step.
Medical image processing are applied to construct 3D models of tracheal structures.

- Computerized Tomography or Magnetic Resonance Imaging define the internal geometry of the tracheal structure → .DICOM file.

- Personalized devices must adapt to the tracheal dimensions found.

- Image-elaboration programs are often used to determine the Region of Interest to work on.

Trasversal Tomography comparison between a carina affected by tracheobronchial malacia and the same carina before the disease became serious.
3D Reconstructions

Image → CAD Model → .STL Repair/Slicing → G-Code → Machine → Material → Stent

.DICOM clinical file
3D Reconstructions

My ITKsnap segmentation of a trachea. The .STL output is on the lower left: it was produced by thresholding and simulating guide lines on the planar images.
With the previous *geometrical* data, model shape can be designed.
3D Reconstructions

My ABAQUS .STL stent model made by rotating the membrane shape sketch and meshing the instance.
Now that we have two .STL models it is possible to view their comparison and fitting with ParaView.

**.STL modeling** is *fundamental*: it is the foundation for those steps that lead to the mere material deposition.
Mesh Repair

- Mesh surface is **discretized**
- To be allowed for printing it must be **manifold**, **watertight**

- **Texture triangles, shell, holes** must be fixed with **repair programs** (netfabb)

Non-Manifold Model vs. Same Model **Manifolded** viewed with **MeshLab**
Path Generation

- Fused Deposition Machine must follow a path while streaming the material
- Decompositions in horizontal layers

Orientation must be determined carefully

Slicing settings and procedure done with Repetier-Host
G-Code

- **G-Code** is a series of instructions written in *machine code*.
- For every formulated **print setting** there's a corresponding **command** in the G-Code.
- The command will be **interpreted** by the machine **software** while printing.

**Settings depending on the shape of the object, polymer chosen, printer components:**

- **Extruder Temperature**
  - `M190 S60;`
  - `set bed temperature`

- **Layer Height**
  - `M104 S200;`
  - `set temperature`

- **Printing Speed**
  - `G1 Z0.300 F9000.000`
  - `perimeters = 1`

- **Perimeter**
  - `external width = 0.50mm`
  - `perimeters extrusion width = 0.04mm`

- **Infill**
  - `fill_pattern = honeycomb`
  - `infill_every_layers = 1`
  - `fill_density = 0%`
The most common 3D printer for polymeric stents is the **Fused Deposition Modeling** machine.

- **FDM** has an **extruder** head nozzle that deposits plastic materials straight out of a plunger.

- Heated **bed** and cooling **fan** modeling

- Deposition follows **G-Code instructions**

- **Real-time control** on many aspects (*feedrate, flowrate, temperature, …*) with softwares like Repetier-Host
The two most popular materials for 3D printing

**ABS**
- Printed Slowly
- Cooled Slightly
- Higher Temperature

**PLA**
- Lower Temperature
- Stable
- Organic Derivative

- These materials can be used for *clinical tools/implants*

- However for stenting purposes *elastomers* (TPU, TPE) or *completely biocompatible* (PLLA, PCL, …) polymers are *preferred*

- *Bioprinting* and *bioink* are studied and represent the future of organ *stenting/manufacturing*
Results

What we obtain at the end of the process in *Proto-Lab*

In **post-processing** many **properties** are checked

- Biocompatibility
- Dynamicity
- Migration Propension
- Insertion Difficulty
- Patient Adaptation
- Surface Accuracy

- **Mechanical** and **fluid dynamics** simulations and tests
- **Imperfections/holes** in the finish are evaluated
Considerations

My 3D printed PLA stent test

• With my work I showed that **3D printing** is a serious reality

• Handling **additive manufacturing** is *intuitive*, but it requires a lot of **on-field experience**

• **Open-Source** machines are making easier the task for **amateurs**

• It can be extremely useful for **medical therapy**

**What can be improved in the near future?**

• **Relationship** strengthening among **medicians / engineers / technicians**

• **Cost reduction**

• **New materials** development to widen the choice for printing

• **General improvement** of the process (**print time, accuracy, ...**)
Grazie per l’attenzione!

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