Università degli studi di Pavia
Dipartimento di Ingegneria Civile e Architettura
Corso di laurea in Bioingegneria

3D Printed Tracheal Stents: overview and open challenges

Relatore: dott. **Michele Conti**
Ringraziamenti: **Gianluca Alaimo** & **Proto-Lab**
http://www-2.unipv.it/compmech/proto-lab.html

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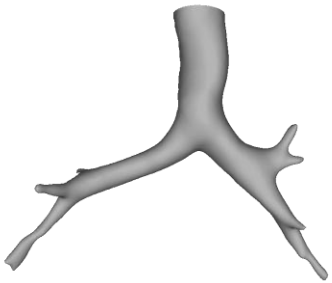
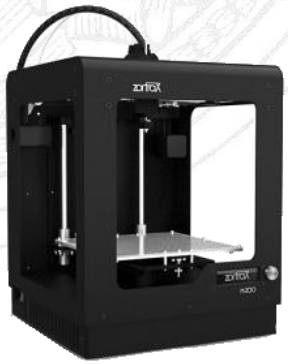
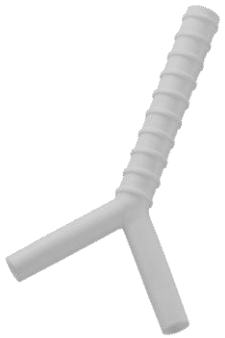
Anno accademico: 2014/2015

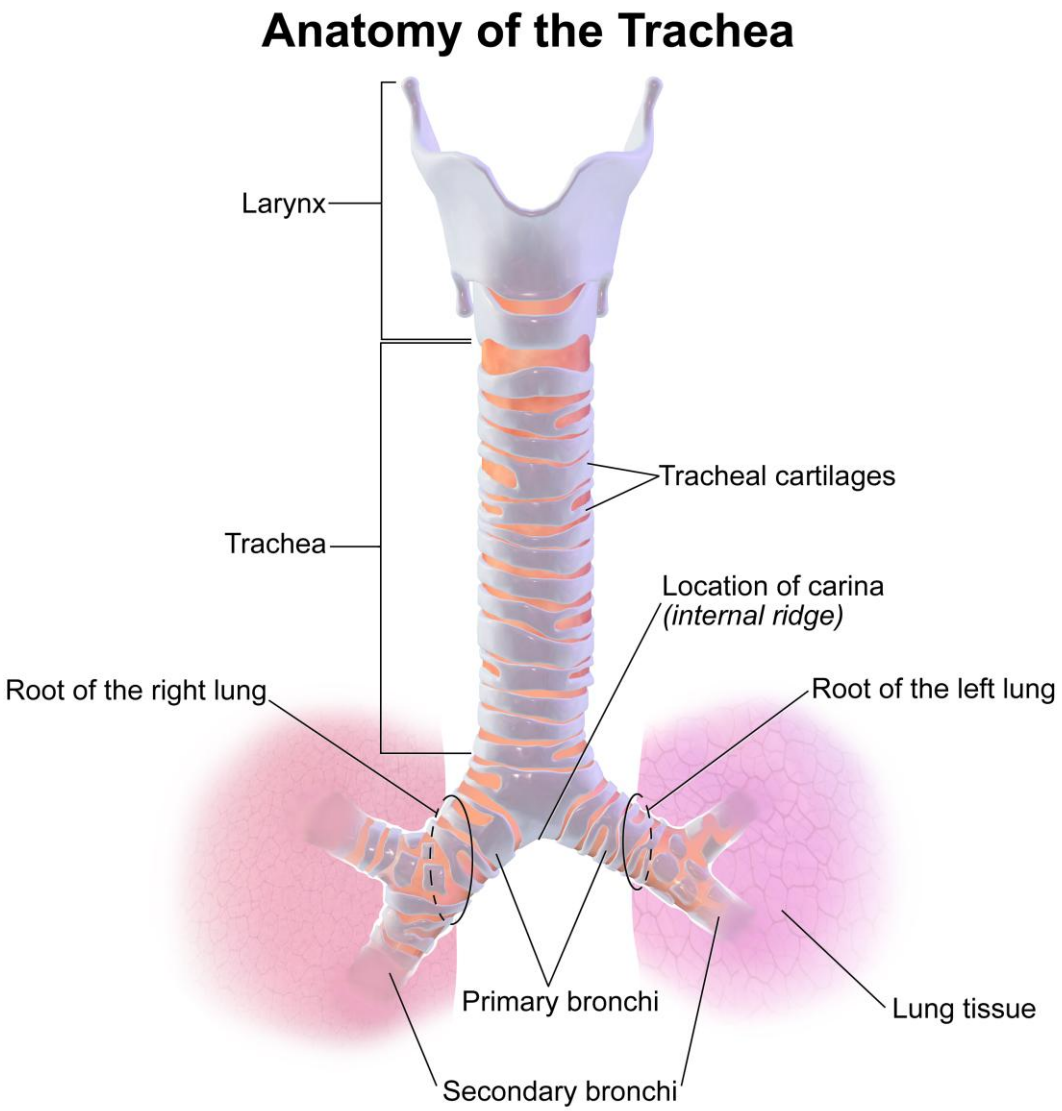
Goals

- 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.

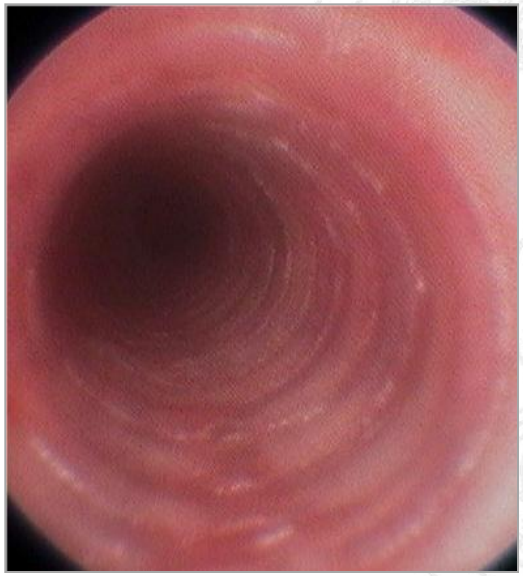
- It connects upper airways (**Larynx**,**Mouth**) with **lungs**

- Cartilaginous **ring** strucuture (open on the back)

- **Cilia** that keep the organ clean along with **mucus**

Clinical Background

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)



Healthy Trachea

CAUSES? EFFECT?

Clinical Background

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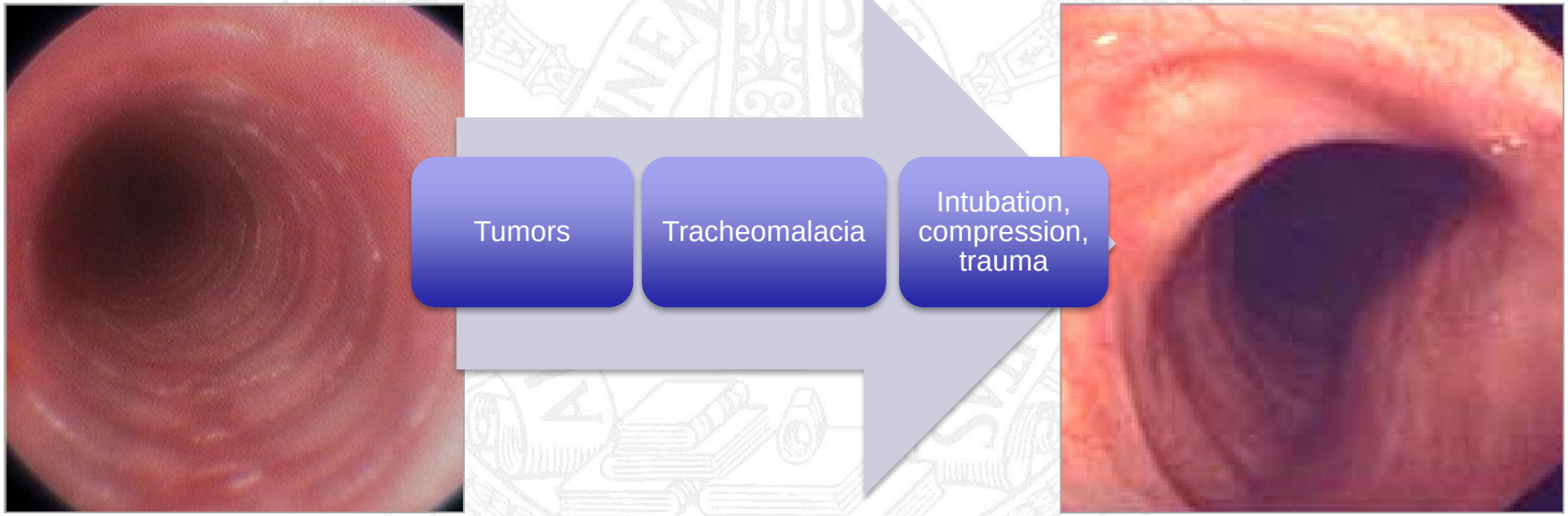


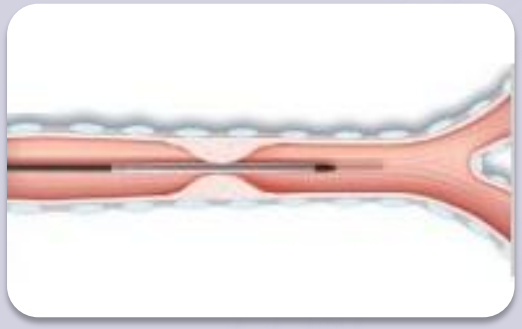
Healthy Trachea

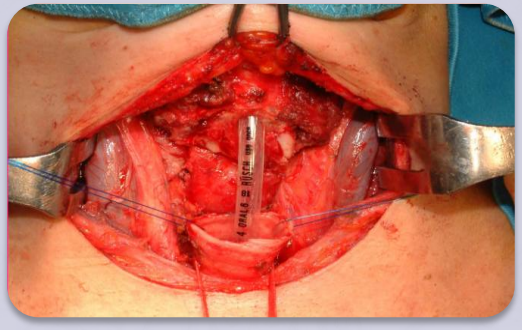
Trachea with *Stenosis*

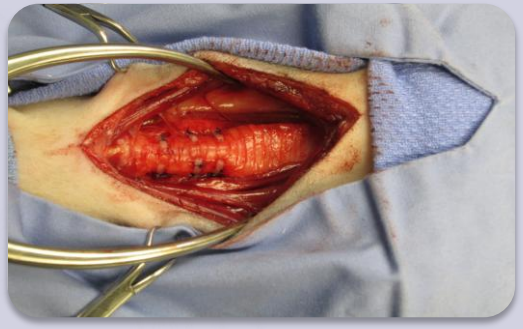
Which are the treatments for stenosis?

Treatment

There are a few types of surgical intervention to treat tracheal stenosis





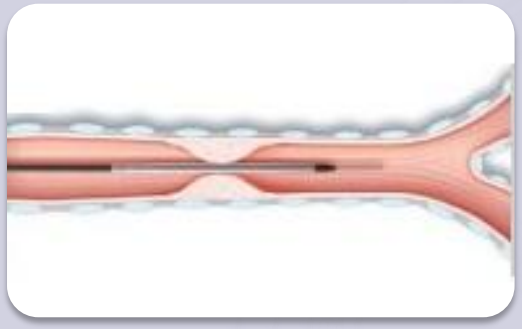


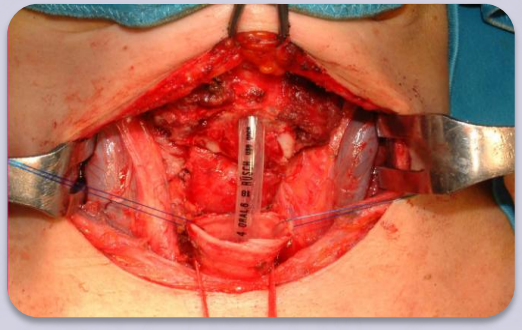
Dilation	Resection	Stenting
• **Temporary** Effect • Possible **relapse** as standalone procedure	• **Re-anastomosis** • **Reconstruction** of the damaged area	• Airway **Support** • **Adaptable**

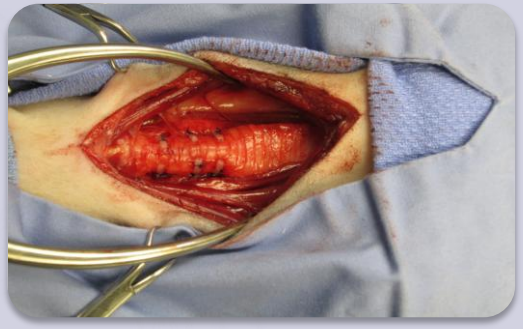
Often these methods are combined (Brichet et al.,1999)

Treatment

There are a few types of surgical intervention to treat tracheal stenosis







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The challenge is to *build* something that can be *adaptable* and *printable*

Stenting

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**

Stenting

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Polymeric

- **Possibility of bioabsorption**
- **Easier to remove**
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- **Migration**
- **Difficult installation**
- **Mucus residue around the stent**

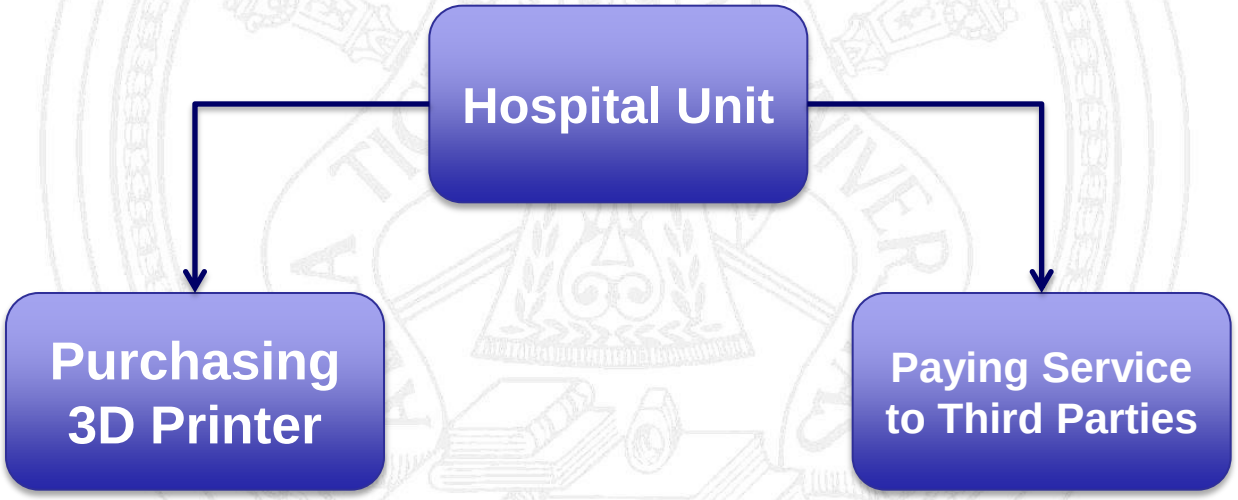
Polymeric stents are the most useful for 3D tracheal manufacturing: *elastic*, *ductile*, *adaptibility-prone*

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 comunities** clinics **can't sustain** the printer's cost and its **derivates** (*materials*, *time*, *energy*)

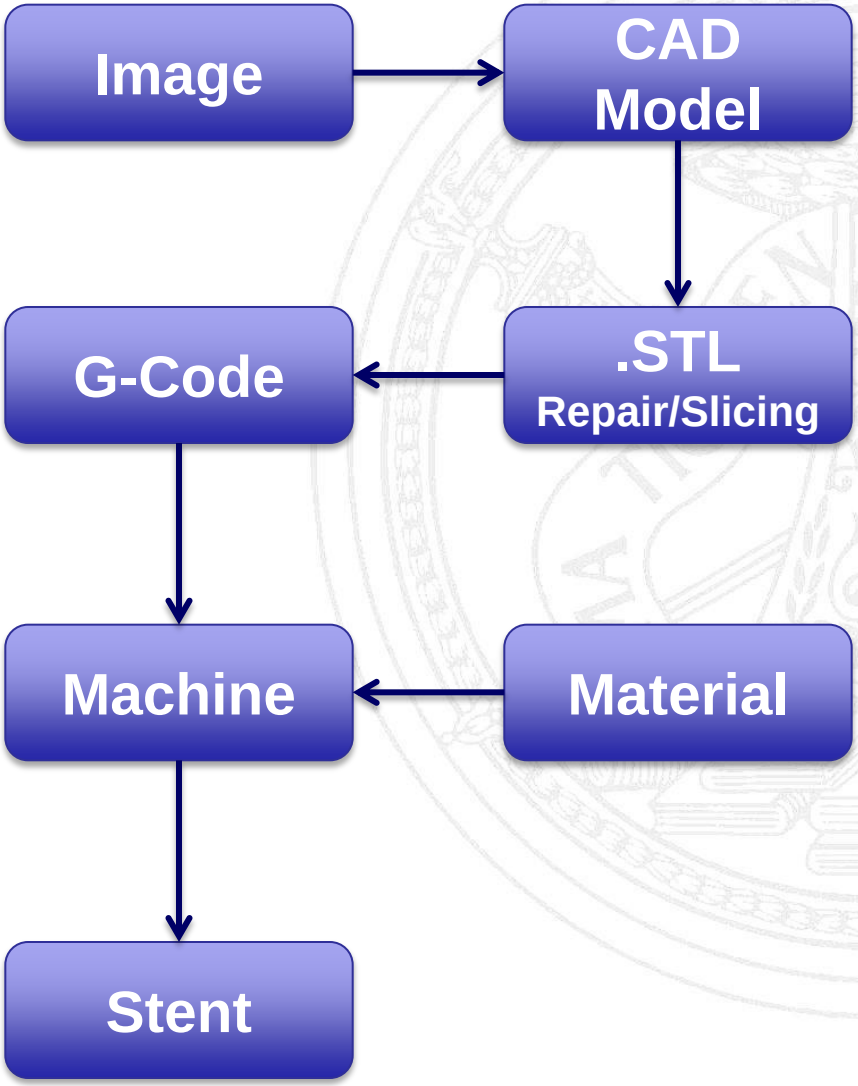
What Clinics Do

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

Schema of the Process

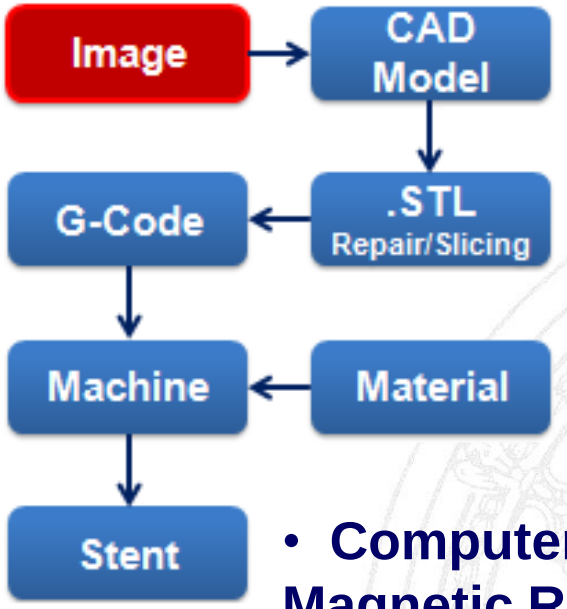
Why do we care studying *Customizable Stents?*



- 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

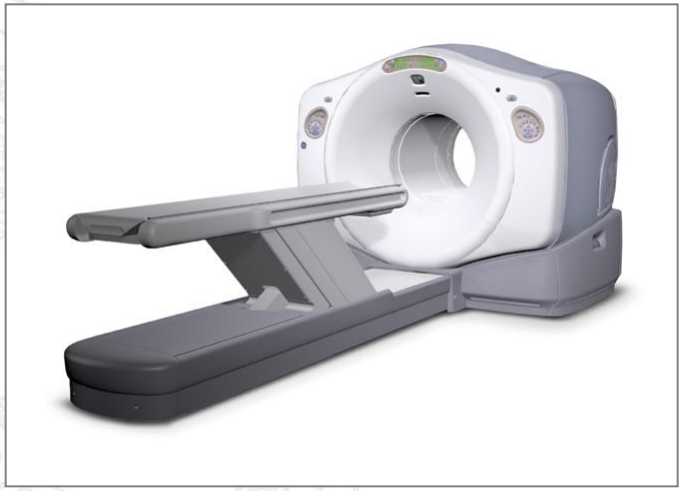
We must analyze each step

Medical Imaging



• **Medical image processing** are applied to construct 3D models of tracheal structures

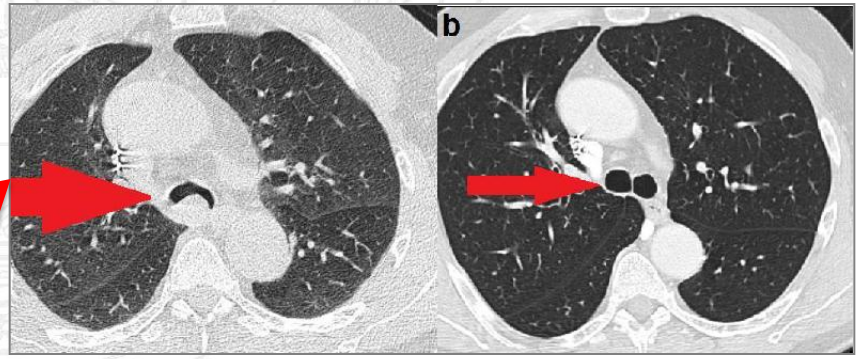
• **Computerized Tomography** or **Magnetic Resonance Imaging** define the internal geometry of the tracheal structure → **.DICOM file**



A MRI Machine

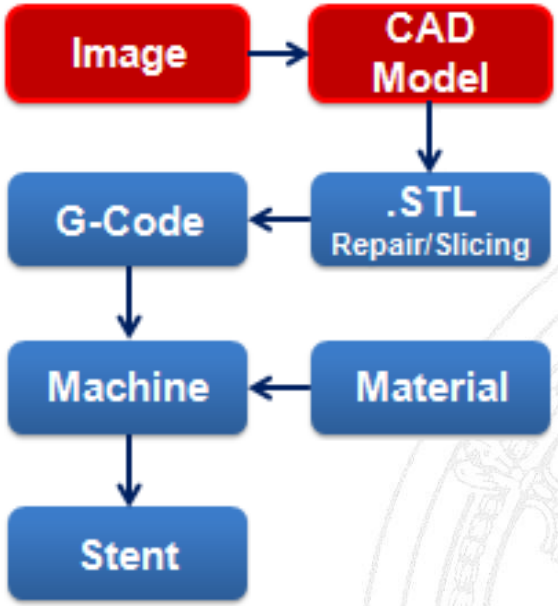
• *Personalized devices* must adapt to the tracheal **dimensions** found

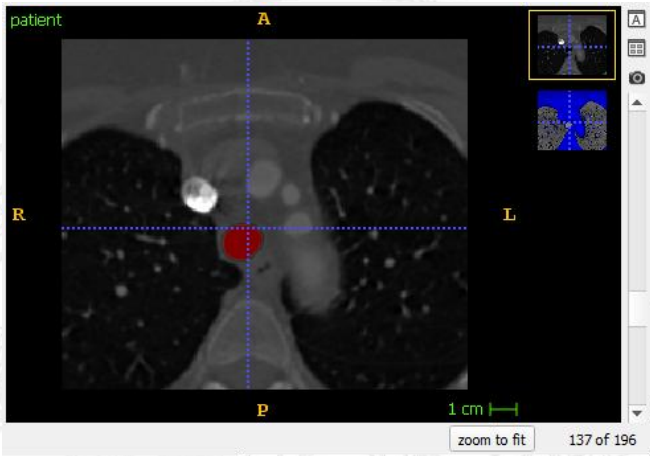
• Image-elaboration programs are often used to determine the **Region of Interest** to work on

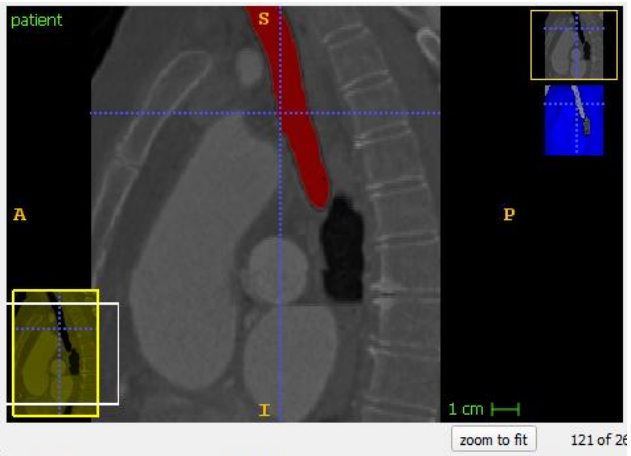


Trasversal Tomography comparison between a carina affected by tracheaobronchial malacia and the same carina before the disease became serious

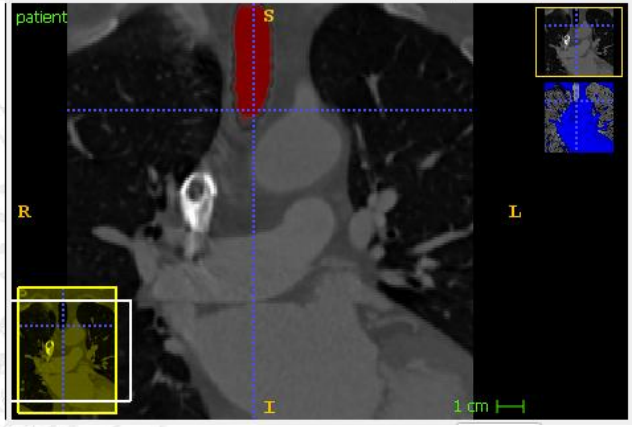
3D Reconstructions



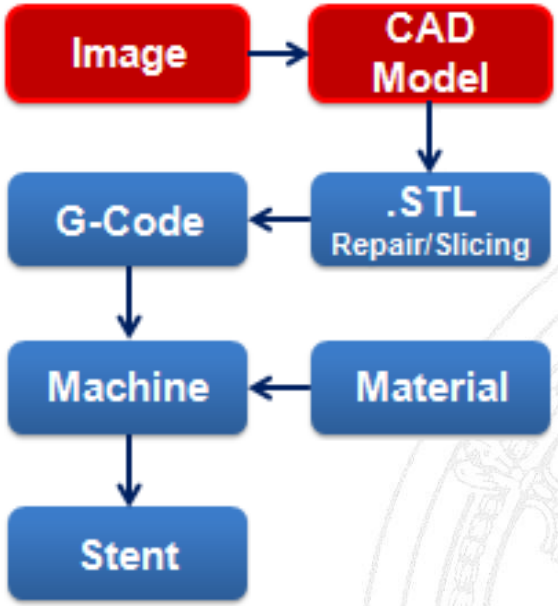


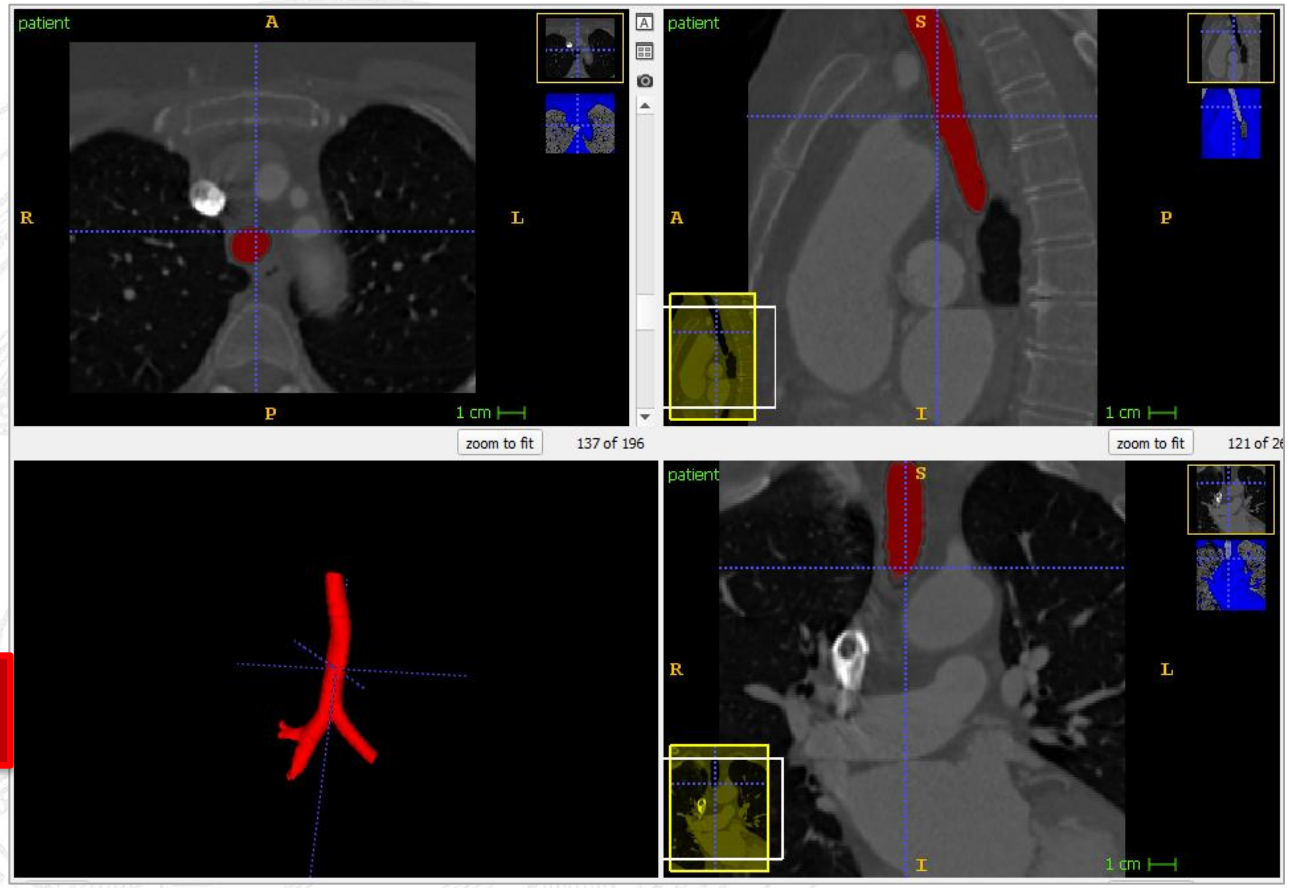


.DICOM
clinical file



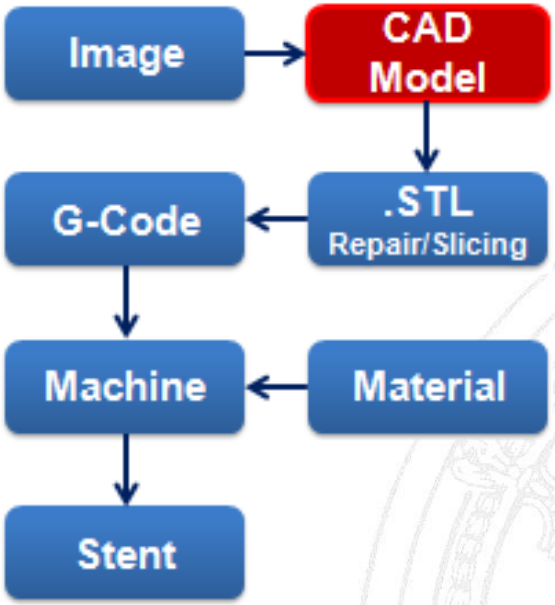
3D Reconstructions

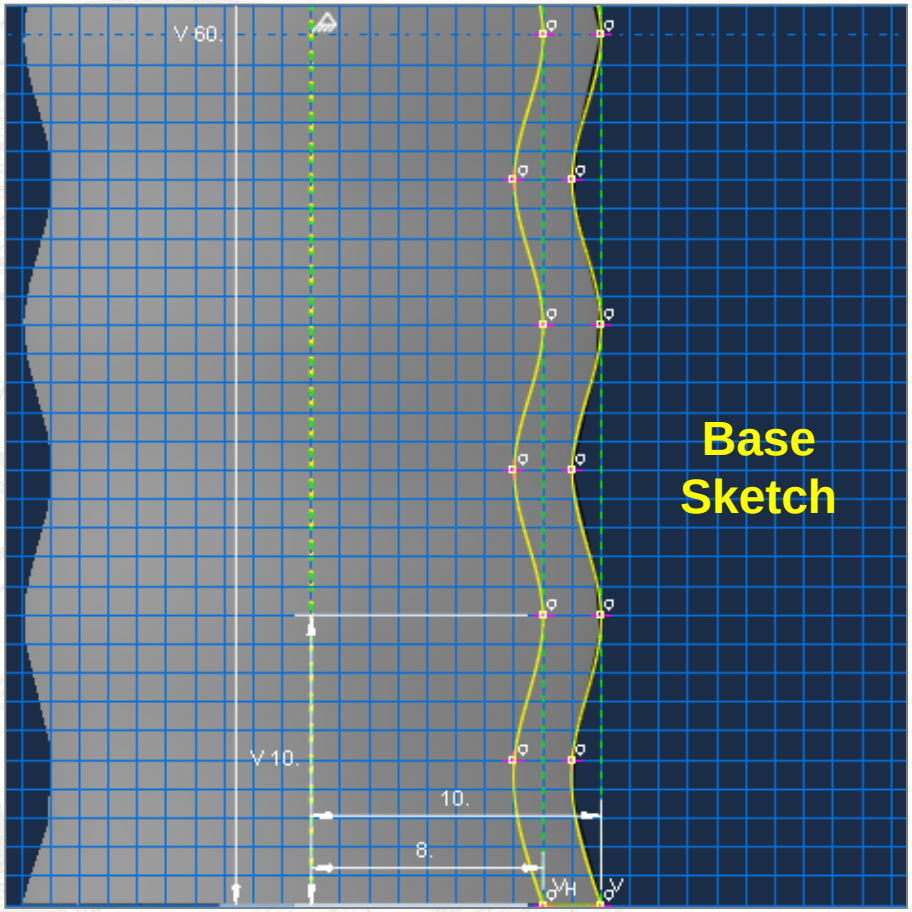




My ***ITKsnap*** segmentation of a trachea. The *.STL* output is on the lower left: it was produced by **thresholding** and **simulating** guide lines on the planar images

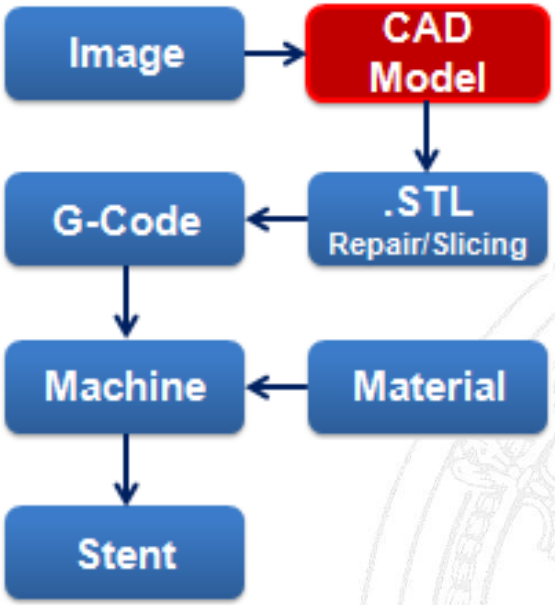
3D Reconstructions

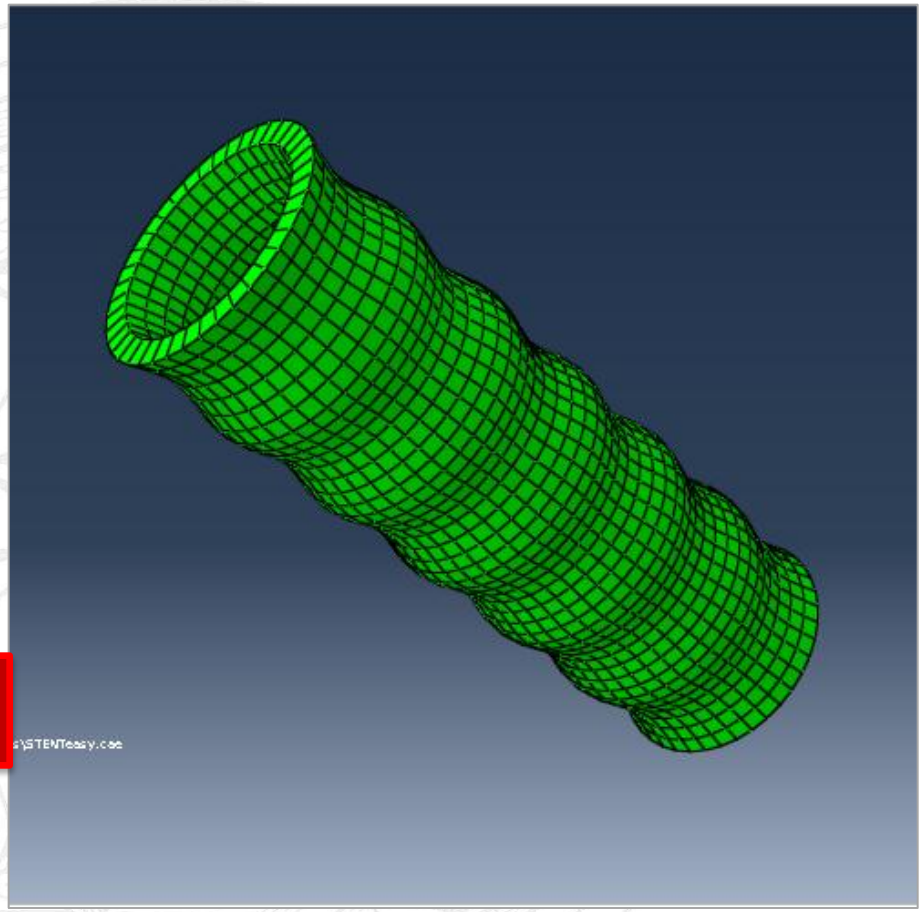




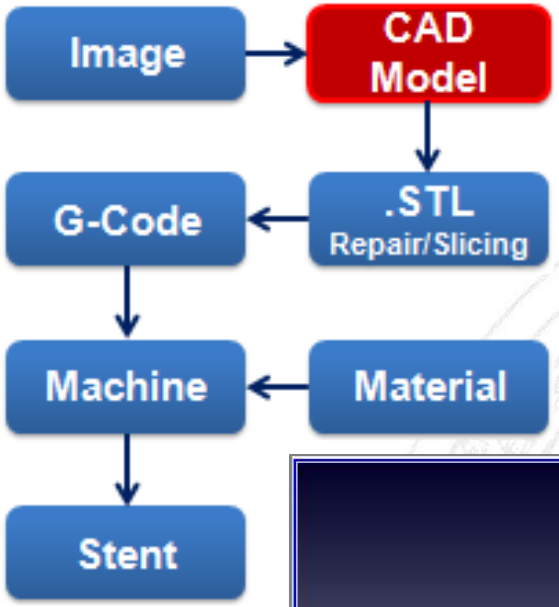
With the previous **geometrical** data, model shape can be designed

3D Reconstructions



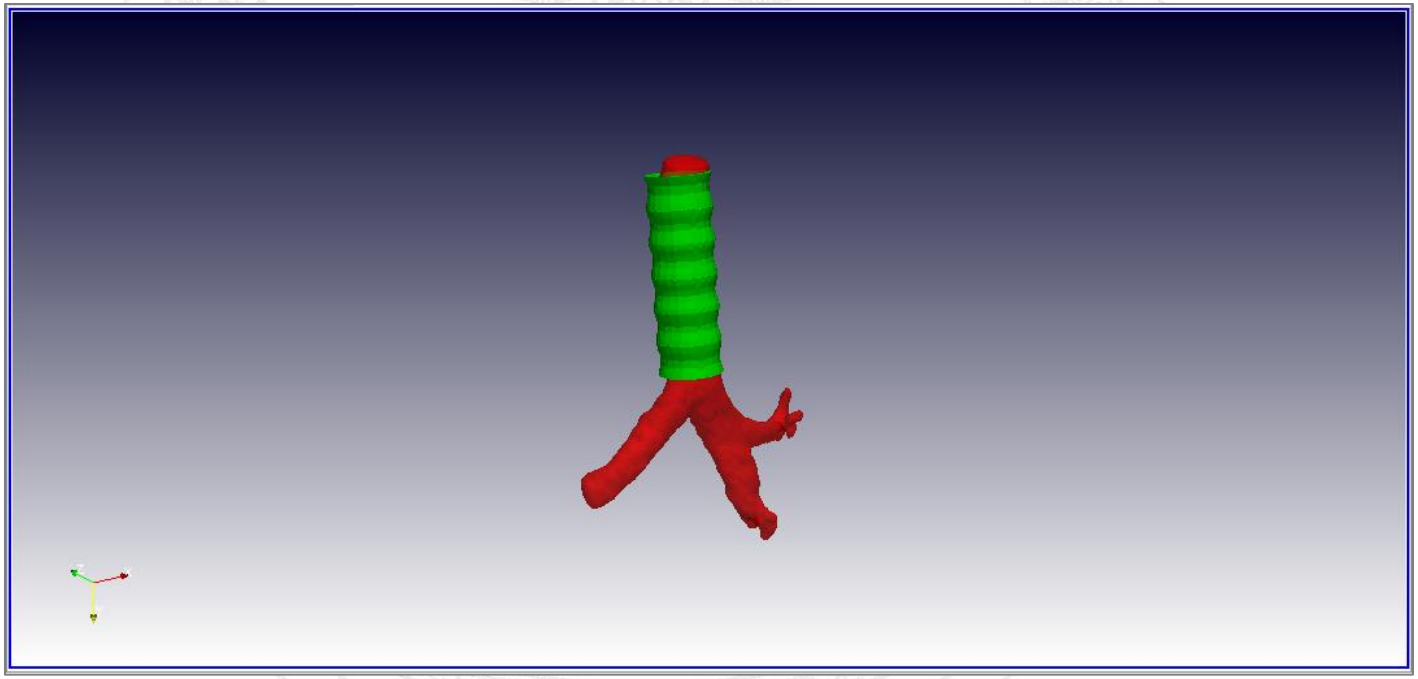


My ABAQUS *.STL* stent model made by **rotating** the membrane shape sketch and **meshing** the instance

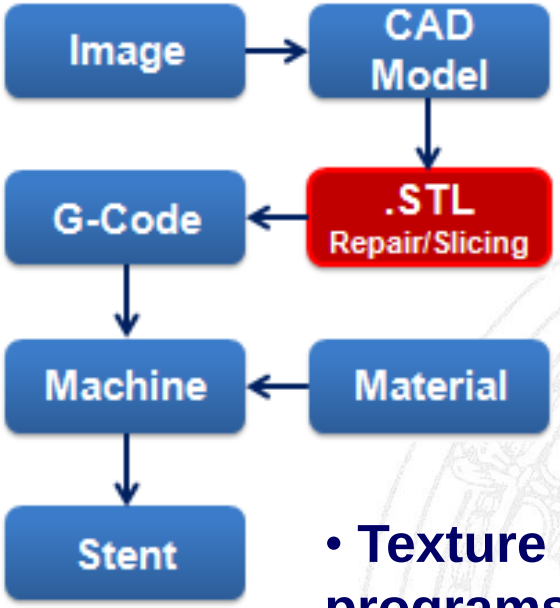


3D Reconstructions

Now that we have two **.STL** models it is possible to view their **comparison** and **fitting** with ParaView

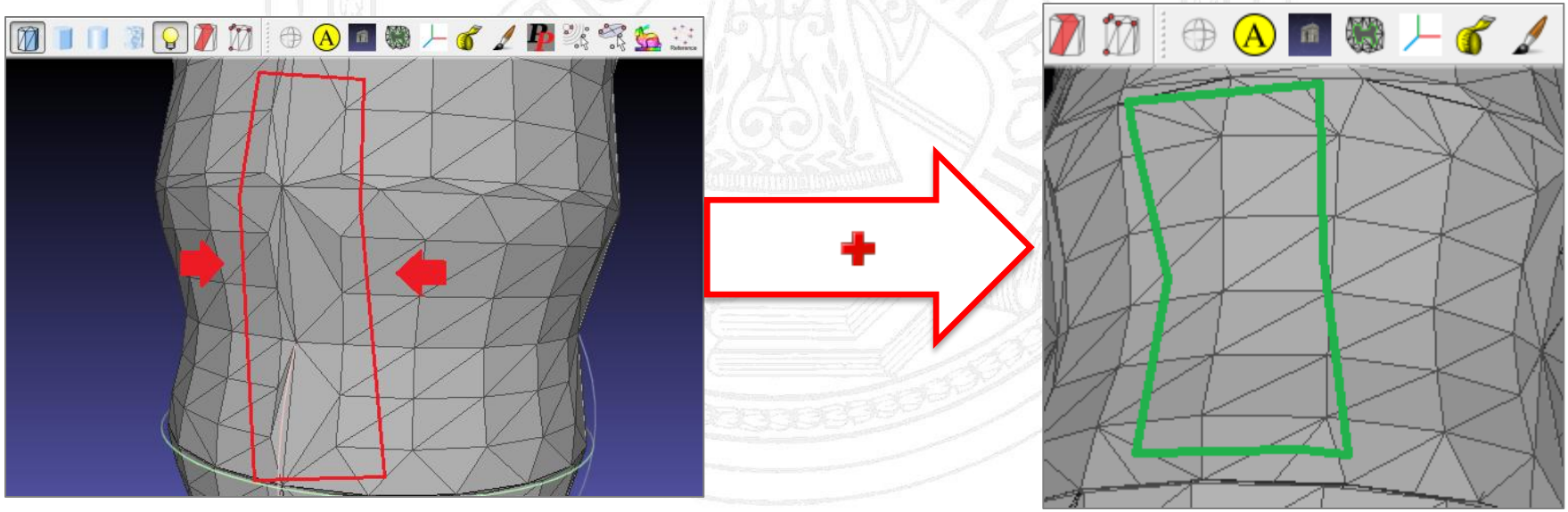


.STL modeling is *fundamental*: it is the foundation for those steps that lead to the mere **material deposition**

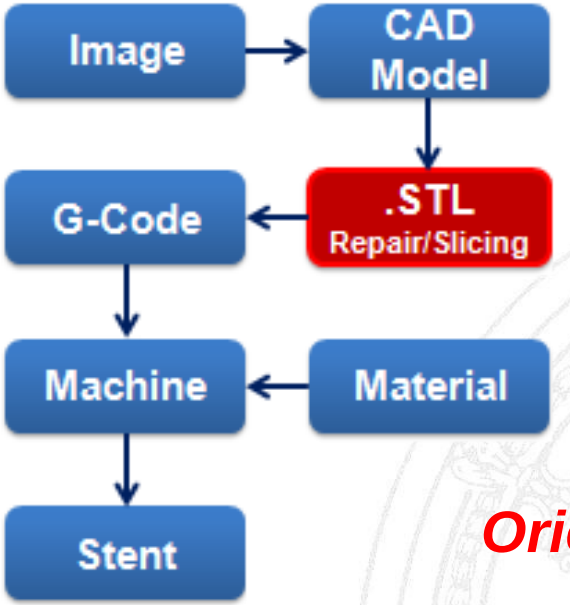


Mesh Repair

- 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**



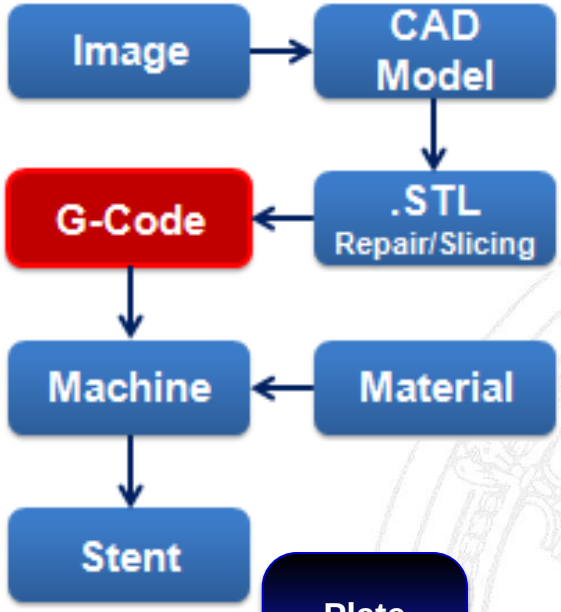
Path Generation

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

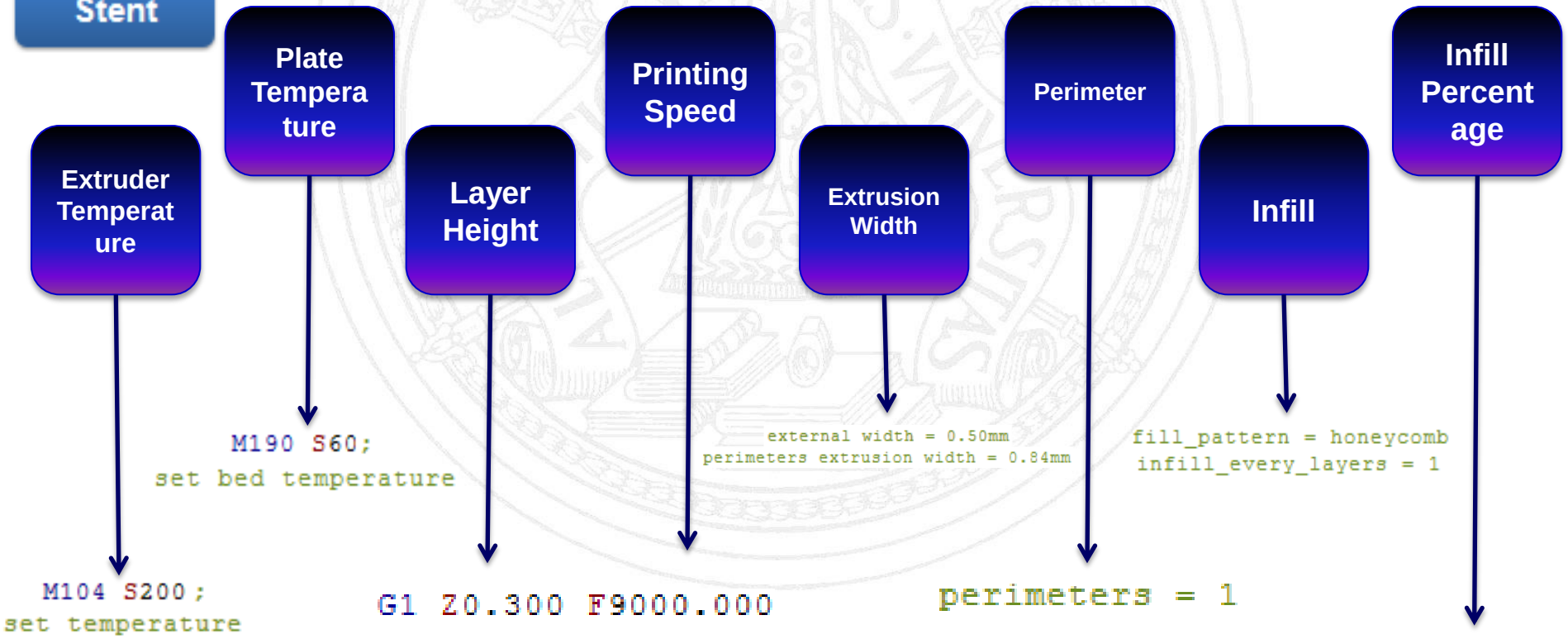
***Orientation* must be determined carefully**

Slicing settings and procedure done with ***Repetier-Host***

G-Code

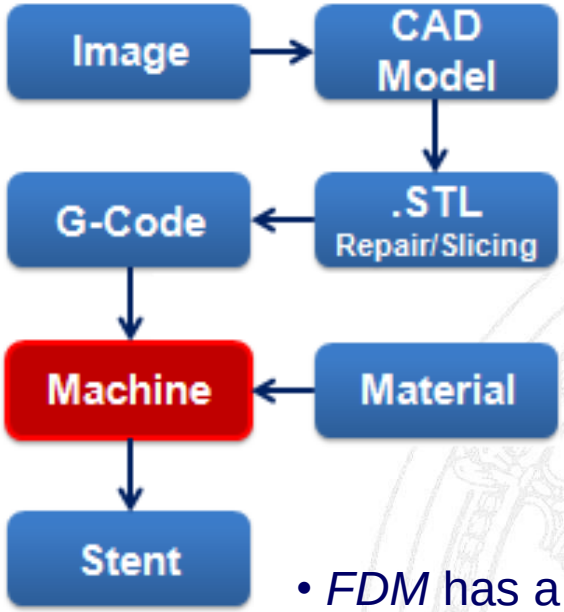


- **G-Code** is a series of instructions written in **machine code**.
- For every formulated **print setting** there's a corresponding **command** in the G-Code
- The command will be **interpreted** by the machine **software** while printing



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

Printing



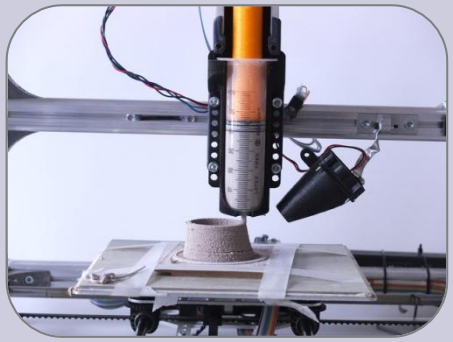
• The most common 3D printer for **polymeric** stents is the **Fused Deposition Modeling** machine

• *FDM* has a **extruder** head nozzle that deposits plastic materials straight out of a **plunger**

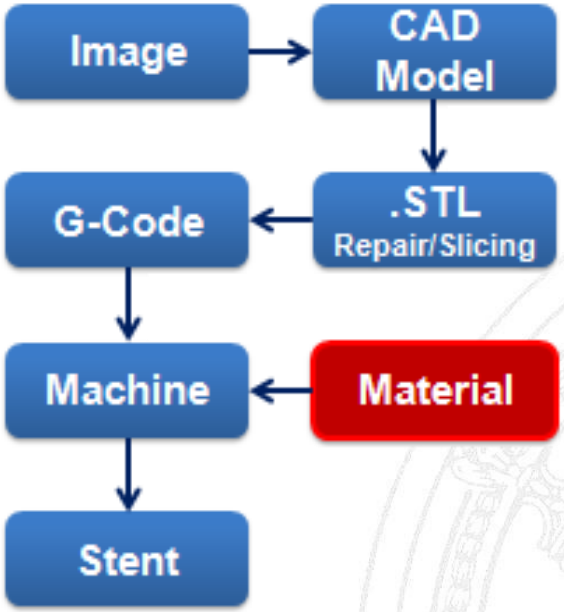
• Heated **bed** and cooling **fan** modeling

• Deposition follows *G-Code* **instructions**

• **Real-time control** on many aspects (*feedrate*, *flowrate*, *temperature*, …) with softwares like **Repetier-Host**

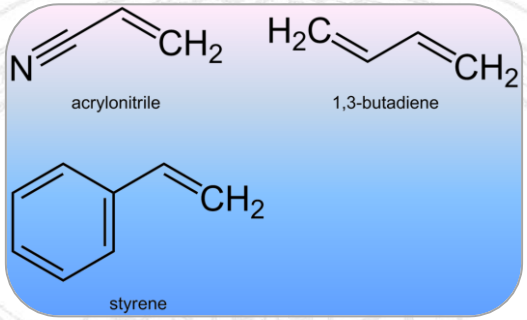


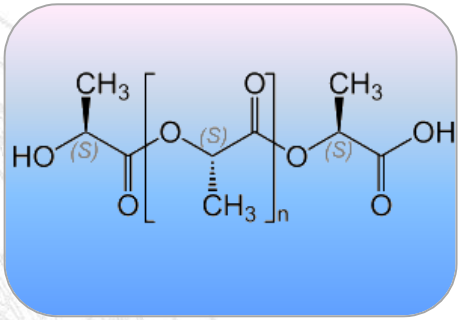
Above: FDM machine
Below: Nozzle tip extruder



Polymers

The two most popular materials for 3D printing





ABS
- Printed Slowly
- Cooled Slightly
- Higher Temperature

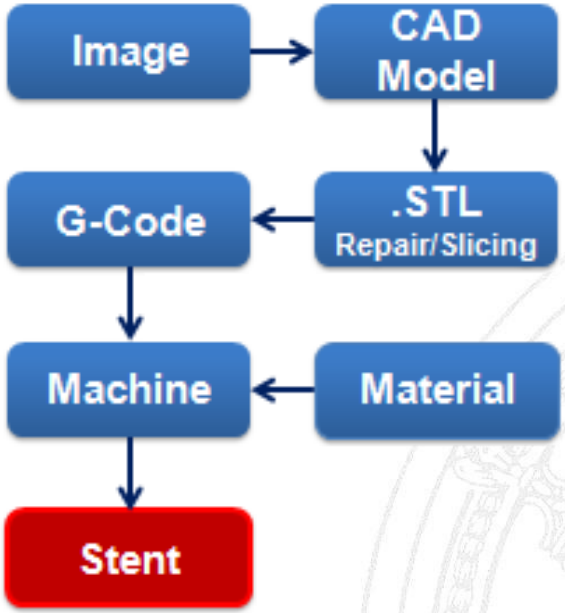
PLA
- Lower Temperature
- Stable
- Organic Derivative

- 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*

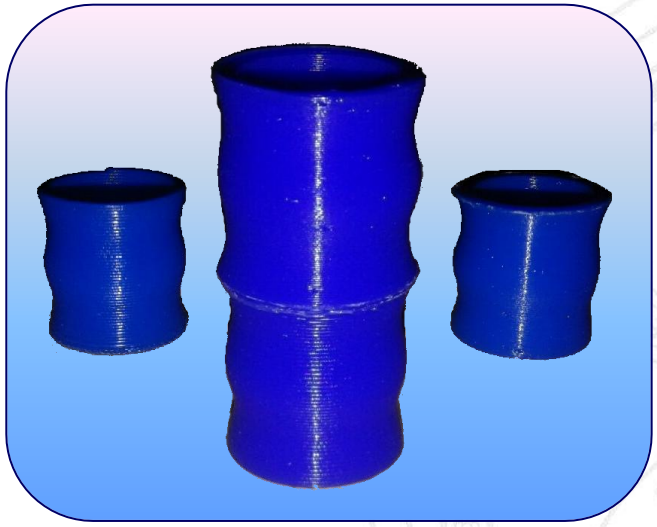
In **post-processing** many **properties** are checked

- **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

Proto-Lab experience



My *3D* printed *PLA* stent **test**

- With my work I showed that **3D printing** is a *serious reality*
- Handling **addictive 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!

Un ringraziamento speciale a *Gianluca Alaimo* e al *Proto-Lab*