Custom 3D Printed Airway Stents

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Background

Stents are used to support airways that are being restricted due to a medical problem such as a tumor or scoliosis. There are four main problems with the current stents on the market: sizing, geometry, migration, and granularity tissue formation. Current market stents are only offered in a select number of sizes and geometries and fail to provide solutions for those that fall outside of this spectrum. Physicians sometimes cut away or stitch together multiple stents to create a makeshift custom stent. When a stent is too small or ill-fitting, it migrates through the airway which can be extremely uncomfortable and often requires a replacement. Ill-fitting stents can also cause pressure points and rubbing in the inhalation/exhalation cycle which allows for granulation tissue formation [1]. These issues are all intertwined and may be resolved by custom airway stents. Advances in 3D printing capabilities and biocompatible materials have made the development of custom stents a more feasible and affordable solution. Our group has documented an end-to-end process beginning with an image and resulting in a printed patient-specific stent which improves upon the available stents on the market.

Route to Patient Specific Stent

- **CT Scan**
- **Physician-Engineer Interface**
- **Airway Segmentation**
- **3-matic**
- **Airway Model and Stent Design**
- **Design Validation**
- **Print and Post Processing**
- **Stent Deployment**

Stent Design (cont.)

Airway Corrections and Adjustments

While CT scans capture soft tissue well, if a patient has an abnormality in the airway the CT scan can't distinguish between the two entities. As a result, segmentation of the airway is not always accurate and some reconstruction is required. Reconstruction can also be used to model the ideal healthy airway.

Airway Model and Stent Creation

The creation of a custom stent varies significantly between patients. The typical workflow includes measuring the area of the airway normal to the center line at key points along the airway (ie. top and bottom of desired stenting area).

Fig. 2. A sequential representation of the virtual reconstruction process of an airway using both Mimics and 3-matic.

Design Validation

To balance the trade off between the risk of migration and the risk of granularity tissue, it is ideal to have a stent that has the most surface contact area with the minimum pressure points.

Print and Post Processing

Both stents and models were printed on a Carbon M1 using continuous liquid interface production (CLIP) technology in Sil30, a biocompatible resin. This allowed for quick iteration of designs and organic geometries.

Testing and Validation

Mechanical Testing

(a) Carbon Printed and (b) Inkjet Printed Models for (a) Stents and (b) MicroCT scans performed to look at print accuracy across 2 different 3D printers of multiple stent designs. The MicroCT, like a medical CT, creates a 3D image of an object using X-ray, but can have resolution on a micron scale. This was used to compare the STL model to the prints to consider the accuracy of the printers.

Fig. 7. Flat Compression for (a) Variable Thickness and Diameter and (b) Variable Thickness and Geometry.

Three sets of 12 stents were tested to determine relative stiffness. Stents were subject to both radial compression and flat compression tests (Test Resources 830LE63 Axial Torsion System). Data can be normalized by dividing obtained stiffness by stent length of 30 mm. The strongest stent had a stiffness of 3.8 N/mm, making it an ineffective material for implementation compared to current market silicon stents.

Fig. 8. Radial (left) and Flat (right) Compression Test Setups

Fig. 9. Stents varied by diameter, thickness, and geometry

MicroCT Print Validation

Additionally, MicroCT scans were performed to look at print accuracy across 2 different 3D printers of multiple stent designs. The MicroCT, like a medical CT, creates a 3D image of an object using X-ray, but can have resolution on a micron scale. This was used to compare the STL model to the prints to consider the accuracy of the printers.

Fig. 10. Radial tests yield higher stent stiffness values than compression tests

Next Steps

We designed a patient-specific route to generate a custom airway stent from a CT image. The next steps will include considering other biocompatible materials that exhibit a higher stiffness required to support the airway that can also be 3D printed. A series of in vivo tests will also be required to test the effectiveness of these custom stents.

Fig. 11. Comparison of (a) Carbon Printed and (b) Inkjet Printed Airway to STL model. (Scale bar is in mm difference between the model and the print.)

References
