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3D printing in the development of an endoscopic probe

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Abstract

In this work we demonstrate the possibility of the development of an optical endoscopic probe. The accuracy of printing of small needle stylet objects of two polyjet printers (Objet 30 Pro, Objet Connex 350) are compared. The minimum outer diameter of the stylet 460 µm is achieved, while the holes in stylets as small as ~400 µm are created. The minimum wall thickness for small objects in the range of 500 µm is achieved. To keep fibers fixed at proximal end of the needle a novel custom made fibers-needle connector was developed. This connector simplifies the clamping of the fibers and connection to the needle.

Introduction

Optical fibers are commonly used for sensing and imaging purposes of the organs of human body in a minimally invasive or non-invasive manner [1]. Recent development of miniature fiber-based probes has a great potential for imaging purposes in medicine [2]. The needle stylet with integrated optical fibers have been demonstrated for infrared spectroscopy [3,4]. The combination of integrated optical fibers with a needle stylet and photoacoustic technology would provide further opportunity for imaging of organ and deep tissue which otherwise wouldn't be possible. For this purpose fibers have to be inserted inside of the procedure needle fixed and constrained against movement. Avoiding cross talk between the fibers they have to be keep apart at some distance. Three-dimensional (3D) printing or rapid prototyping (RP) technology has been widely used in the varieties of scientific areas: biotechnology, medical science, chemistry, dentistry and others [5-10]. The direct formation of the object (layer by layer in sub mm scale), freedom in object design, multi-material printing, and minimum lost material during production are some of the interesting capabilities of 3D printing. It provides an opportunity for engineers to create unique complex structures, visualize the designed objects before the construction and eliminate errors, and saving material. The knowledge of printing accuracy (resolution) of small parts is required.

In this context the feasibility of 3D printing technology for the development of needle stylets and endoscopic probes is assessed. We will demonstrate the latest progress in development of endoscopic probes with help of 3D printing.

Methodology

Needle stylets

The needle stylets of different diameters (0.6mm-3mm) in the form of cylinder with holes were designed using two freely available software programs: FreeCAD (Juergen Riegel, Werner Mayer, Yorik van Havre, OpenSource, freecad.com) and Blender (Stichting Blender Foundation, Amsterdam, the Netherlands) (See Fig.1a). STL files of designed needle stylets were exported and sent for printing. The stylets designed to hold fibers inside of the needle were printed with highest possible resolution by two 3D printers Objet 30 and Objet 350 Connex (Stratasys, Eden Prairie, Minnesota) using polyjet technology. More information on this and other 3D printing techniques can be found at www.3d-med.co.uk. The Objet 30 printer can fabricate the components using Verowhite (VeroWhitePlus RGD835, Stratasys) material only, but there is an option for gloss or non-gloss type of printing, meaning it will print without or with supporting material respectively. The Objet 350 Connex printer has an option to print parts using two materials at the same time rubber and plastic (VeroWhite/VeroClear and TangoBlack). Moreover it allows choosing the hardness of both materials used.

The stylets printed by Objet 350 were dipped in an ultrasonic bath with bleach for 10-15 minutes, and then the supporting material was removed using small brushes. The small diameter lumens within the stylets were cleared of supporting material with stiff piano wire (Hugh Craig Harpsichords, Gloucester, UK). The stylets using Objet 30 were printed in gloss mode where no support is applied to the top surface of the model. In this option there is no need in piano wires as there is no supporting material in the holes. The finished stylets were measured using digital calipers. Standard deviation calculation and error bars were plotted using Matlab and Origin softwares. The holes in the stylets were observed and measured using a stereo microscope with digital camera (Leica Microsystems Ltd, UK).

Probe development

An optical probe was developed using two step-index, silica-core/silica-cladding multimode optical fibres with core/cladding diameters of 105/125 µm. One fiber could be used for deliver laser emission while the other for acquiring a response signal with a Fabri-Perot sensor at the tip for example. In order to keep both fibers 100 µm distance apart a guide wire was used. One end of a 360 µm guide wire was crushed down to 100 µm thickness to allow two fibres be placed on each side of the wire. Then heat shrink tubing (Heat shrink, Vention Medical, Salem, NH, USA) with inner diameter of 0.021"+/-0.001" and with wall thickness of 0.00100"+/-0.0002" was placed over two fibres and wire. After applying heat above 820 °C by a heat gun the tube shrinks 15-20%. The other end of the wire was clamped by a 3D printed holder. The whole assembly was placed inside of an 18 Gauge needle (Terumo Corporation, Tokyo, Japan) with 1.27 mm outer diameter. The needle and two fibers with guide wire were connected using 3D printed custom design holder. Several holders were designed and printed using both printers Objet 30 and Objet 350 Connex (see Fig.5). The needle was fixed at one end of the holder while the fibers and guide wire were clamped on the other side using two pads and plastic screws. In addition, at the bottom pad special grooves were made to secure the fibers in place. Objet 350 Connex printer had allowed printing extra layer of 2 mm thick rubber on the bottom plastic pad to decrease the movement between the fibers and the pads.

Results and Discussion

The possibility of fabrication of 3D printed needle stylet has been investigated. A number of needle stylets-cylindrical objects with one or two holes have been fabricated as shown in Fig.1 b, c.

The outer diameter was ranging from 0.6 mm to 3 mm. The tip of every object was tilted 22 degree from z direction similar to the needle stylet. The height of the objects was ranging from 10 mm to 50 mm. The samples were printed vertically from bottom to the tilted tip of the object. 3D printed objects with different outer diameter, diameter of hole and wall thickness were investigated.

The minimum outer diameter of the stylet 460 µm was achieved (Fig. 1c), while the holes as small as ~400 µm can be printed. Outer diameters of the cylindrical objects were measured and percent errors from the designs were calculated and plotted (Fig.2). The percent error from design decreases from 30% as the diameter increases for Objet Connex 350 printer. The samples with more than 1.5 mm diameters have been printed with 4% accuracy using both printers in X and with 15% accuracy in Y directions. The diameters of the 3D printed samples are slightly higher than specified in the design. It was found that stylets with the outer diameter less than 1.6 mm are very delicate and fragile. The samples with the diameters less than 1mm, were not strong enough if there were printed by Objet Connex 350. Only using Objet 30 Pro it was possible to print the objects of such dimension with 5-8% error in X and Y directions. The samples printed by Objet 30 Pro have shown better accuracy overall.

The accuracy of printing holes by both printers have been investigated as well. The minimum diameter of the hole ~400 µm was able to print. In the samples printed in non-gloss regime the supporting material was pushed away using piano wires. It is clear that by printing in gloss regime with Objet 30 Pro the results are more accurate and predictable as there is no need of removing the supporting material. In general, the percent error reduces as the diameter of the hole increases, the real holes are smaller compared to the design.

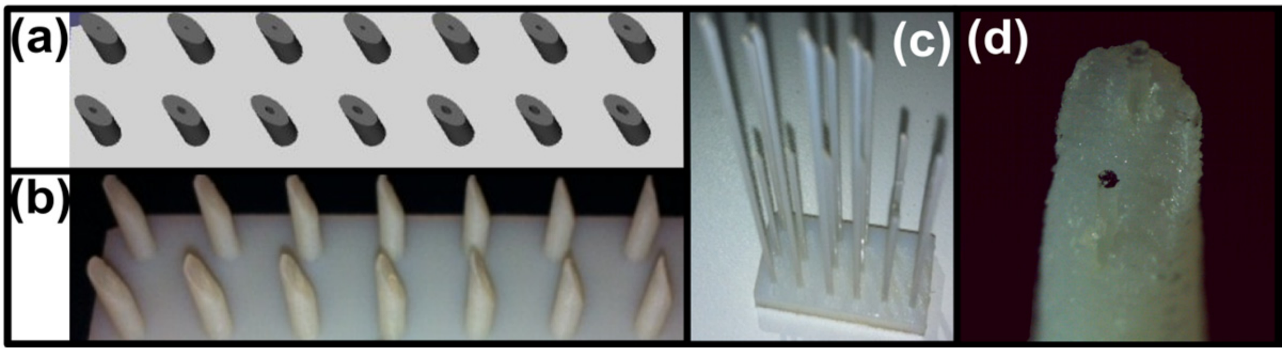

Figure. 1 (a) *3mm cylinder objects (stylets) with 22 degree at the tip are designed in FreeCAD software,* ***(b)*** *fabricated by Objet 350 Connex 3D printer and* ***(c)*** *by Objet30 Pro with minimum outer diameter of 460 µm.* ***(d)*** *The possibility of two 125 µm fibers to keep apart using 3mm diameter 3D printed stylet at the proximal end of the needle is demonstrated.*

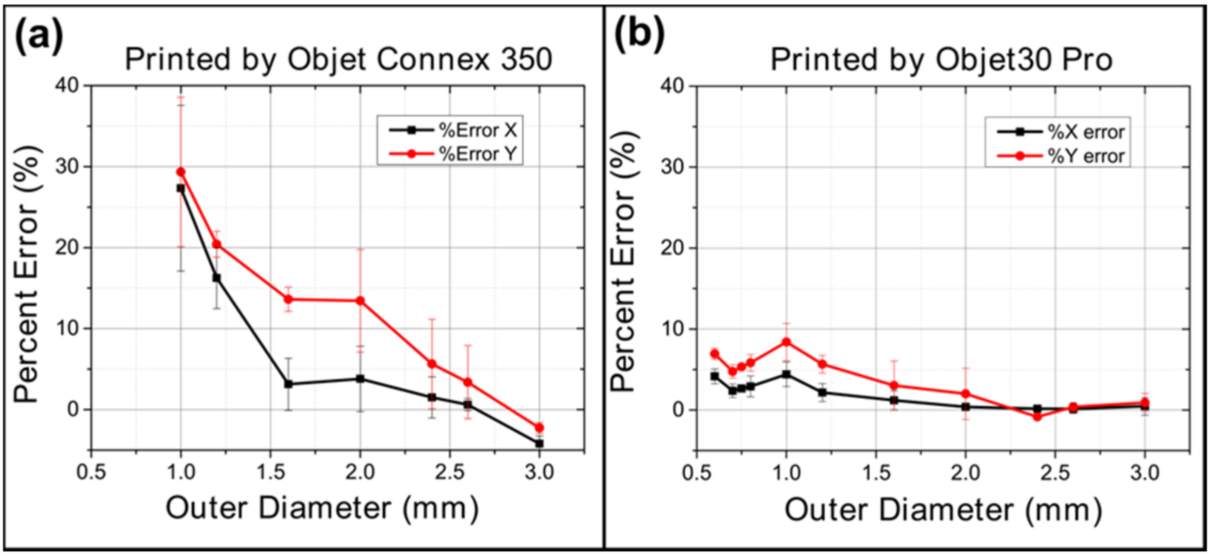

Figure 2*. Percent error 3D printed cyllindrical stylets (outer diameter) 0.6mm-3mm by* ***(a)****Stratasys Objet 350 Connex (Bartlet),* ***(b)*** *Stratasys Objet 30.*

The objects with wall thickness from 50 µm to 500 µm with the height of all objects of 20 mm have been designed and fabricated using Objet 30 Pro in gloss regime. As shown in Fig.3 the objects with wall less than 300 µm were not printed completely. The height of the objects was only few mm. There is an error from what was designed and what was fabricated. The planned wall thickness of 300-350 µm ended up in 450-500 µm. The optimum wall thickness for small objects is more than 500 µm.

Several holders were designed and printed using 3D drawing software FreeCAD which were used to connect the needle with two fibers at distant end of the needle as shown in Fig.4. The needle is connected on the right hand side and fibers are clamped on the left hand side using plastic screws. There are grooves in the left pad of the connector for fibers. The accuracy of printing depends on width of the grooves. The grooves (400µm-1.1mm) printing accuracy or percent error decreases from 18% to 5% for plastic material and for rubbery material grooves (600µm-1mm) printing accuracy decreases from 23% to 5% while for grooves below 600µm printing error randomly changes between 10%-30%.

Objet 350 Connex printer has allowed to print an extra layer of the rubber above the plastic. It was found that fibers are less slippery on rubber.

For optical probe development two fibres inside of the 130 mm long 18 Gauge needle need to be incorporated, but unfortunately, the 3D printed stylets longer than 10cm vertically or horizontally are very fragile. Overall when the samples are not printed in vertical direction the samples are less accurate and more fragile.

Label	N	Wall plan um	Wall real um	Height, um	Plan Height um
a	1.1	50	420	6.3	20
b	1.2	100	420	9.2	20
c	1.3	150	370	13.4	20
d	1.4	200	390	16.2	20
e	1.5	250	390	18.7	20
f	1.6	300	450	19.7	20
g	1.7	350	500	20.02	20
h	1.8	400	550	20	20
i	1.9	450	580	20.03	20
j	1.10	500	610	20.02	20

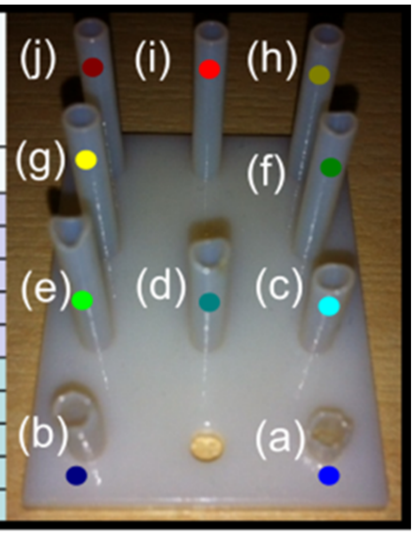

Figure.3 *Objects printed by Objet 30 Pro with wall thickness **(a)** 50 µm, **(b)** 100 µm, **(c)** 150 µm, **(d)** 200 µm, **(e)** 250 µm, **(f)** 300 µm, **(g)** 350 µm, **(h)** 400 µm, **(i)** 450 µm, **(j)** 500 µm.*

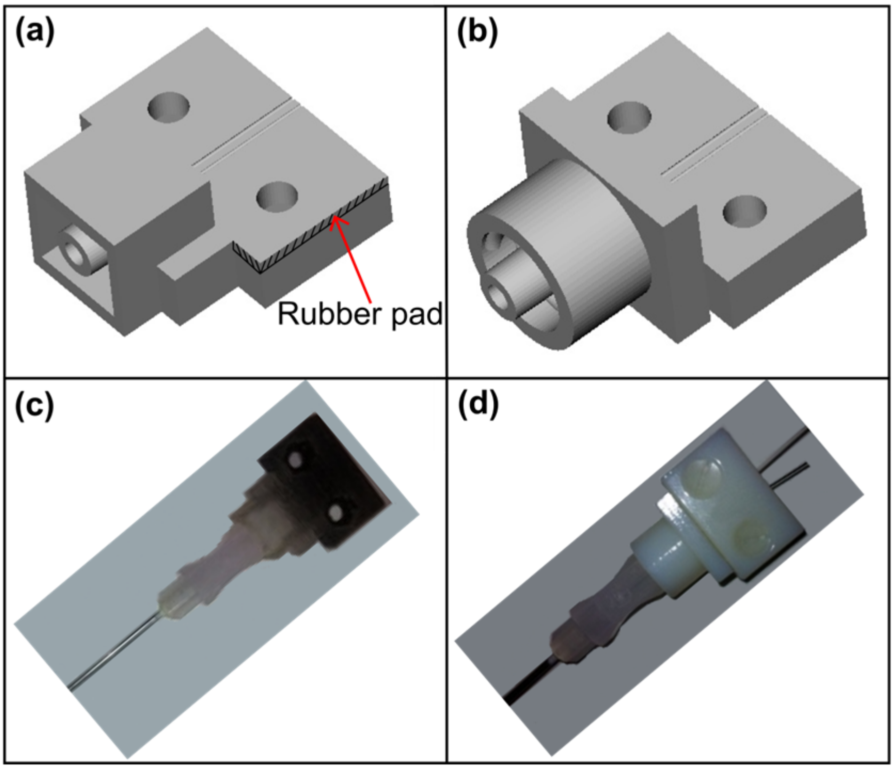

Figure 4 (a), (b) *Designs of the customized fibers-needle holders with grooves for fibers and a luer lock for the needle connection, **(c)** fabricated by Objet 350 Connex printer, and **(d)** fabricated by Objet 30 Pro printer with minimum outer diameter of 460 µm.*

But still the interventional optical probe can be developed as demonstrated in Figure 5. Two multimode fibers hold together with heat shrink tube with the piano wire in the middle to avoid the cross talk and increase the robustness of the assembly, which was inserted inside of an 18 Gauge needle.

Conclusion

The feasibility of using 3D printed stylets have been investigated. The results show that Stratasys Objet printers allow printing cyllindrical objects as small as 460 µm diameter, minimum wall thickness ~500 µm, and minimum holes size printed was ~400 µm for both printers. The advantage of Objet 30 Pro is gloss printing regime as no post cleaning required. Custom needle-fibers connectors were designed and fabricated by both printers. It is not practical to print long stylets as they are too fragile regardless of the orientation of the print. An alternative method of fabrication optical probe comprising of two optical fibers inside of 18G needle was shown.

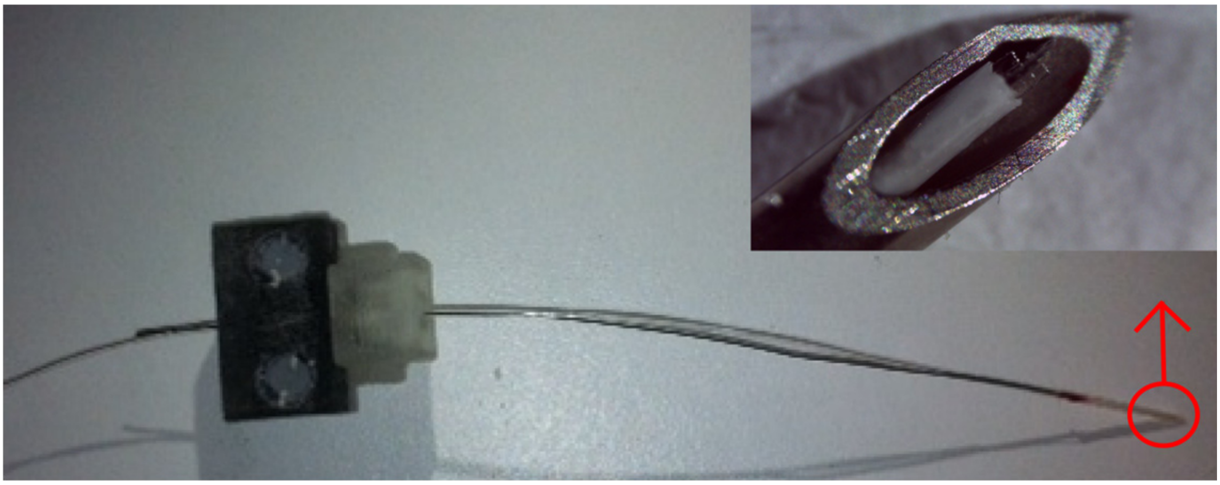

Figure 5 *Interventional optical probe with apple type 3D printed stylet, inset: The stylet of 2.4mm diameter with two 250 um fibers*

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3D printing, optical probe, needle stylet

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Daniil Nikitichev has earned a PhD degree from University of Dundee (2012) in Laser Physics. The same year he joined the University College London in London, UK. He has been working with a photoacoustic ultrasound system for ex-vivo and in-vivo imaging of the tissues and organs. His research topics include 3D printing, acoustic properties of 3D printed materials, acoustic sensors, photoacoustic imaging, optical and photoacoustic phantoms.