Design of 3D-printable nasopharyngeal swabs in Matlab for COVID-19 testing

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Abstract: As an important diagnostic device for detecting respiratory infections, the nasopharyngeal swab is running out of supply due to the fast spread of COVID-19. In this short paper, we present a novel design platform in Matlab for realizing patient-specific nasopharyngeal swabs that can be quickly 3D-printed to fill the swabs' shortage. Firstly, the swab is realized with our geometry modeling tool using the size derived from the patient's CT data. Then, Selective-Laser-Sintering (SLS) is employed to print the swab using polyamide as biocompatible material. A printed swab is also presented to demonstrate the performance of the proposed design platform.

I. Introduction

Since its first outbreak in Wuhan, China, in December 2019, the coronavirus disease 2019 (COVID-19) has spread worldwide, resulting in a pandemic that affects the life of everyone [1]. An important diagnostic device for the testing of COVID-19 is the nasopharyngeal (NP) swab, which is a long and flexible stick used to collect mucus samples from the nasopharynx, a region of the pharynx that covers the roof of the mouth (see Fig. 1). However, due to the rapidly increasing number of infection cases and the transport restrictions between countries, the supply of testing swabs for hospitals is becoming increasingly scarce [3]. On the other hand, most swabs in the market only have one standard size, which has not taken the different nostril sizes of patients into account and hence, could cause pain to some patients during the testing procedure. From this point of view, patient-specific NP swabs are also highly desirable. To cope with these problems, we have developed a design platform in Matlab for achieving patient-specific design of NP swabs. The realized swabs can be quickly 3D-printed using biocompatible material, which helps to relieve the pressure on the supply chain of swabs.
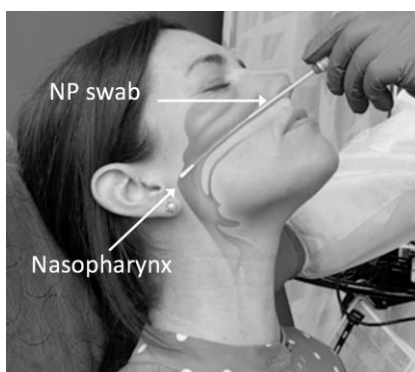

Figure 1: Collecting respiratory samples using a NP swab [2].

II. Design methods

In this section, we introduce the methods used in our design platform: determining the size of the nasal passage from patient's CT data, geometry modeling for creating 3D-printable models, and finite element analysis (FEA) for evaluating the mechanical performance of the swabs.

II.I. Size determination of the nasal passage

An important feature of our patient-specific design is that the size of the swab is derived from the nasal passage size of the patient. Fig. 2 shows a computed tomography scan of the nasal cavity of a patient in the sagittal plane, where the three nasal meatuses (passages) can be clearly addressed. The length l and diameter d_i of the inferior nasal meatus are measured, since the NP swab goes through this passage to collect the respiratory samples. We have integrated the processing of the patient's CT data into a single Matlab function so that the size of the nasal passages can be measured automatically.
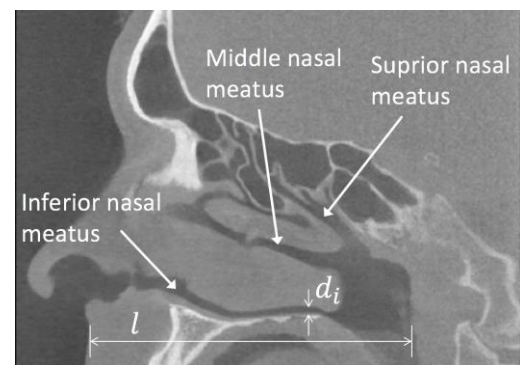

Figure 2: A computed tomography scan of the nasal cavity, which is visualized in Matlab to measure the size of the nasal passages.

II.II. Geometry modeling

Since the standard file for 3D-printing, the STL-file, is

based on boundary representation (B-rep), we employ surface models in our design framework to model the geometry of the swabs. In this way, the realized swab can be directly 3D-printed without the data conversion between different types of geometry files, which greatly simplifies the design process and avoids the loss of information during the conversion process [4]. A detailed description of our B-rep-based geometry modeling tool can be found in [5].
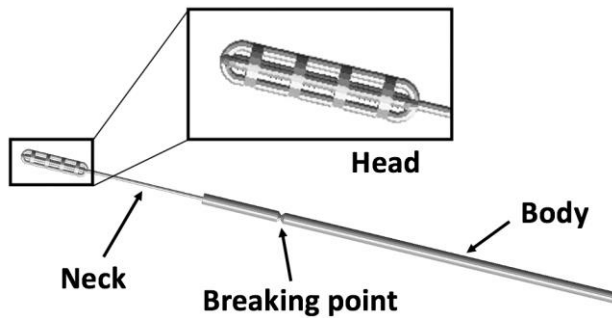

Figure 3: The realized surface model of a NP swab.

Fig. 3 presents an example of a realized NP swab. As can be seen in the figure, the basic geometry is comprised of a porous head, a flexible neck and a holding body. The diameter and length of the head are equal to d_i and $0.25l$ respectively, so that the swab causes less pain to the patient and sufficient respiratory sample can be taken. As the polyamide (PA2200) [6] is used as Selective-Laser-Sintering (SLS) material to fabricate the swabs, the diameter and length of the neck are chosen as 1mm and $0.5l$ respectively, to make the neck flexible. The holding body has a diameter of d_i so that it will not get stuck at the opening of the nostril. A thin breaking point with a diameter of 0.5mm is intentionally constructed on the holding body so that the front part of the swab can be broken after collecting the sample and then capped to be transported to the testing laboratory. The distance between the swab tip and the breaking point is set to l to reduce the risk of breaking the swab in the nasal passage. In the example swab of Fig. 3, l and d_i were set to 70mm and 3.5mm respectively, taken from the CT data of a patient.

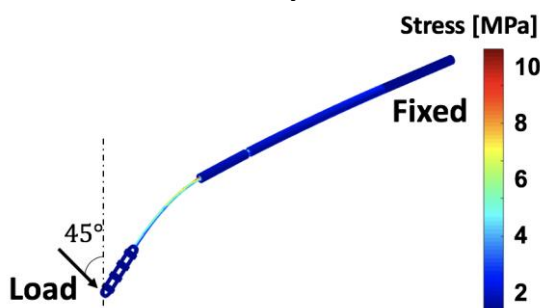## II.III. Finite element analysis

Figure 4: The FEA result showing the deformed shape and stress distribution of a loaded NP swab.

Before printing the swab, we also use FEA to evaluate the mechanical performance of the design proposal. The FEA is based on large-displacement finite element formulation, which is also implemented in Matlab [7]. Fig. 4 presents the FEA result of the loaded swab in Fig. 3. The bottom of

the holding body is fixed, while the load is applied on the tip of the swab with an angle of 45° to the z-axis to mimic the resistance of the nasopharynx during the sample collection. The result shows that the most deformations and stresses were located in the flexible neck and there was no large deformation at the breaking point. In this way, a safe testing procedure could be achieved that causes little pain to the patient.

III. 3D-printed prototype

The example swab in Fig. 3 was SLS-printed and post-processed so that the surface of the swab was smooth and also biocompatible. Fig. 5a) shows the printed prototype. The deformed shape of the flexible neck in Fig. 5b) has validated the FEA result in Fig. 4, which demonstrated the good mechanical performance of the printed swab.
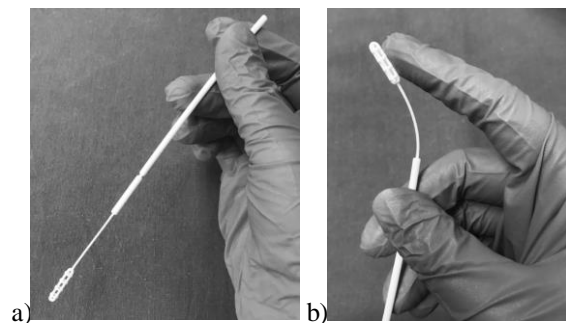

Figure 5: The SLS-printed swab prototype: a) Original shape of the swab, b) The elastically deformed flexible neck of the swab.

IV. Conclusion

In this short paper, we presented an efficient framework in Matlab for designing patient-specific NP swabs for COVID-19 testing. The design principle and procedure were illustrated by an example. FEA was used to evaluate the mechanical performance of the design proposal. A SLS-printed prototype was also presented to demonstrate the functionality of the realized swab. In future work, more experiments, such as the fatigue tests, should be carried out to further analyze the mechanical properties of the printed swabs. On the other hand, the realized swabs should also be fabricated with other 3D-printing technologies, such as the stereolithography printing, to deeply explore the potential of the presented design framework.

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