

# Preliminary Study on a 3D Printed Sensorized Probe to Characterize Pituitary Adenoma Hardness

Giacomo Santona  
Department of Information Engineering  
University of Brescia  
Brescia, Italy  
giacomo.santona@unibs.it

Tiziano Fapanni  
Department of Information Engineering  
University of Brescia  
Brescia, Italy  
tiziano.fapanni@unibs.it

Antonio Fiorentino  
Department of Mechanical and  
Industrial Engineering  
University of Brescia  
Brescia, Italy  
antonio.fiorentino@unibs.it

Francesco Doglietto  
Neurosurgery Department of  
Neuroscience, Sensory Organs and  
Thorax  
Fondazione Policlinico Universitario A.  
Gemelli, Catholic University School of  
Medicine  
Rome, Italy  
francesco.doglietto@unicatt.it

Mauro Serpelloni  
Department of Information Engineering  
University of Brescia  
Brescia, Italy  
mauro.serpelloni@unibs.it

**Abstract**— Endoscopic endonasal transsphenoidal surgery approach, is a new surgical technique used by otolaryngologists and neurosurgeons to resect pituitary adenoma (PA). The most challenging aspect is related to the fact that the strategy of the resection changes according to the hardness of PAs, which is mostly soft, but it can also be harder (fibrous adenoma). This work proposes a first attempt to develop an alternative and innovative sensorized probe capable to discern the different hardness of soft materials. The proposed solution can be implemented in training models in order to give feedback to the users. The probe was developed thanks to additive manufacturing Fused Filament Fabrication (FFF) technology. Inside the probe there is a magneto resistive sensor and a magnet that is glued on the tip in order to measure the variation of the magnetic field linked to the movement of the magnet. After a preliminary electrically characterization of the probe, tests were conducted with three different silicones with slightly different Shore A attested hardness in order to verify if the probe is able to discern the materials. The first results show a high repeatability with a mean variation  $< 1\%$ . Future work will be conducted with ex-vivo samples of pituitary adenomas in order to characterize their hardness and to classify the different types of PAs with a hardness parameter, and also to find the best material to mimic the consistency for training models.

**Keywords**— transsphenoidal surgery, training models, pituitary adenoma, hardness, probe, magneto resistive sensors.

## I. INTRODUCTION

Endoscopic endonasal transsphenoidal surgery is a new minimally invasive surgical procedure used by otolaryngologists and neurosurgeons to access the pituitary gland directly from the sella turcica to resect pituitary adenoma (PA) [1]. In this frame, the level of hand-eye coordination and the experience needed to optimize the results of surgery is significant. This results in a steep learning curve for endoscopic endonasal transsphenoidal surgery [2]. An additional complication is given by the fact that the strategies to resect pituitary adenomas change according to their consistency which in most case is soft or, less frequently, hard (fibrous adenoma) [3]. As stated by Acitores Cancela et al. in their work [4], the main difference between soft and fibrous PAs is that soft PAs can be easily removed with an aspirator, while fibrous PAs require prior fragmentation, resulting in a more technically challenging

procedure. For these reasons it is required a specific training to surgeons before entering the operating room, so they can learn to handle both cases. Nowadays the gold standard for training residents is still simulating an operation on human cadaveric heads, whose lack of pituitary adenoma was overcome by injecting a resin into a cadaveric head [5], [6]. On the other hand, 3D printed models offer an interesting alternative to cadaveric heads training, but still cannot replace them due to the lower anatomical fidelity [7]. Nevertheless, 3D printed training models are gaining momentum, and PAs have been mimicked with soft boiled eggs [8]–[13], a solution of ballistic test material and water [14] or silica gel [15]. The material is chosen according to surgeons experience gained through the year on the field. However, what is missing is an evaluation of the mechanical properties of PAs that can provide information to make the process of choosing the right material for mimicking PAs easier and more effective. Moreover, the use of standardized materials could improve resident training through more repeatable and accurate simulation with 3D printed training models. The main problem of the determination of mechanical properties are mainly related to the position of the tumor, however, Bekeny et al. in their analysis of the forces registered during a resection of a pituitary adenoma with a transsphenoidal approach stated that the level of forces applied during the surgery ranged from 0.1 to 0.5 N during excision of pituitary lesions [14]. In addition, in the literature, the work of Stewart et al. [16] proposes a mechanical characterization performed with a sensorized indenter to determine the consistency of brain tumors with a steady-state modulus parameter defined by the authors themselves.

This paper describes the development of an innovative sensorized probe, which is designed to provide information on the hardness of PAs. The sensorized probe consists of two parts: a rigid body that provides stability to the system and a highly deformable tip. Using 3D printing technology Fused Filament Fabrication (FFF), it was possible to fabricate rapidly both rigid and deformable part, with chosen materials. The mechanical structure was integrated with a magneto resistive sensor and a magnet to estimate the deformation of the tip when a stress is applied, and so to evaluate the hardness of different materials. The device is proposed to provide an alternative, easy to understand measure of the

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hardness of soft materials. Furthermore, this sensorized probe can be used to find the best substitute, for both soft and firm PAs, to implement in a training model. This goal will provide a more realistic training experience and real-time feedback to surgeons who are approaching such a challenging surgery for the first time.

## II. MATERIALS AND METHODS

### A. Concept of the sensorized probe

The idea of the probe is to measure the hardness of materials by measuring the variation of the magnetic field with a magneto resistive sensor placed inside the device and a magnet glued to a highly-deformable tip. When pressed against a surface, the tip compresses, causing the magnet to move and to get closer to the sensor. The variation of the magnetic field related to the decreasing relative position between the sensor and the magnet is measured by the sensor's output. Ideally, if the tip is pressed with a known displacement against a non-deformable material, the displacement of the magnet is maximum, and its value is equal to the displacement imposed. For example, if the probe is pressed against a metal surface of 1 mm, the overall displacement of the magnet is equal to 1 mm, since the deformation of the tip is maximum. However, when the tip is pressed against a softer material, the total displacement of the magnet is less than 1 mm due to the deformation of the soft material. It is therefore possible to compare the different hardness of the materials. This behavior can be modelled by two springs in series, where the equivalent force applied is equal for both springs, while the compression is higher for the one with a smaller spring constant. By performing a specifically designed displacement control test, i.e. with 1 mm indentation, it is possible to obtain indirectly a parameter that estimates the hardness of the tested material. Thanks to the high deformability of the tip, the probe is suitable to discern the hardness of different soft materials.

### B. Device Design

The probe was designed on SolidWorks (Dassault Systèmes, France). It consists of two parts: a rigid body whose function is to provide stability to the whole probe and a deformable five-armed tip. The body is a 50 mm long hollow

cylinder with 5 grooves all over it. The inner diameter is 4.6 mm while its thickness is 1.9 mm. The five grooves are designed to allow better coupling between the body and the tip. The tip is a five-armed thin structure with a circular plate in the middle to allow placement of the magnet. The thickness of the tip is 0.7 mm while the length and the width of its arms are respectively 30 mm and 1.4 mm. The model of the tip is shown in fig. 1 (a). The tip is folded and glued to the body as shown in fig. 1 (b). Both the body and the tip were fabricated using the Fused Filament Fabrication (FFF) Ultimaker 3 Extended (Ultimaker, Utrecht, Netherlands) 3D printer. The STL models were then processed with Cura software (version 5.22). The body and the tip were 3D printed using Ultimaker Pearl-White PLA and Ultimaker TPU 95A filaments respectively. A board, with a TMR2905S, a Ultra High Sensitivity sensor (50~60mV/V/Oe), soldered to, is 4.2 mm width, and it is inserted within the body, meanwhile a cubic magnet with a side of 1 mm is glued in the middle of the tip, the movement of the magnet, due to the deformation of the tip, is measured as the variation of the magnetic field. Fig. 1 (c) shows the probe mounted on a computer-controlled micrometric slide ready to perform a test. The choice of the magneto resistive sensor was made with a view to future development. The idea is to design a new surgical instruments capable to detect the hardness of soft tissue. The sensor is suitable since it can be hermetically closed to prevent it from coming into contact with anything, leaving out only the magnet, which can be easily sterilized.

### C. Device Characterization

A preliminary characterization of the magnet-sensor distance curve was performed using a computer-controlled micrometric slide to move the magnet from a maximum distance of 20 mm to contact (distance 0 mm) with the sensor in 300  $\mu\text{m}$  steps. After reaching the minimum distance, the device was raised in 600  $\mu\text{m}$  steps. Then, in order to provide a preliminary characterization of the proposed device, the same computer-controlled micrometric slide, equipped with a load cell, was used to compress the device from its rest position which was found to be at a distance of 7 mm to the

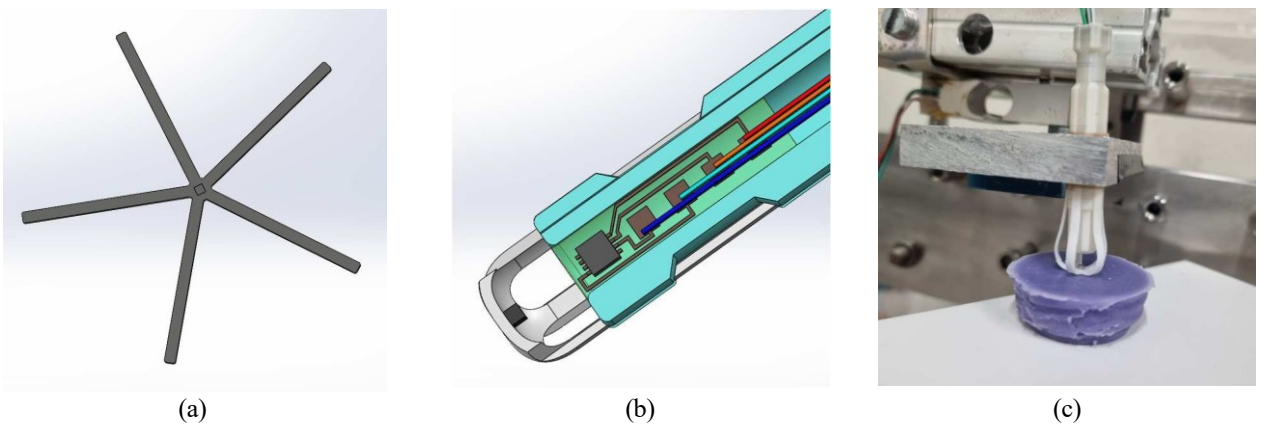


Fig. 1. The tip (a) is a five-armed thin structure with a circular plate in the middle to allow placement of the magnet. A section of the sensorized probe (b) shows the relative position of the TMR2905S and the magnet. The probe consists of two parts: the body whose function is to provide stability to the whole probe and a five-armed tip. The body is a 50-millimeter-long hollow cylinder with 5 grooves all over it. The inner diameter is 4.6 mm while its thickness is 1.9 mm. The thickness of the tip is 0.7 mm while the length and the width of its arms are respectively 30 mm and 1.4 mm. Both the body and the tip were fabricated through Fused Filament Fabrication (FFF). The probe is mounted on a computer-controlled micrometric slide and it is ready to perform a test (c).

maximum compression at a distance of 2 mm in 300  $\mu\text{m}$  steps. Those values were chosen in order to provide a good sensitivity of the device in its working range. For both the hereby described experiments the sensor was biased at 1 V by means of an adjustable laboratory power supply according to the manufacturer's specifications, while the micrometric slide was alimanted at 10 V. Before starting the experiments, a static characterization of the load cell was carried out to obtain its calibration curve. This resulted linear ( $R^2 = 0.999$ ) with a sensitivity of 4.35 N/mV. The output voltage was measured by means of an HP34401a (Hewlett-Packard, Palo Alto, CA, USA) digital multimeter sampled by a custom LabVIEW virtual instrument at 1 Hz.

#### D. Proof of Concept

The device is tested using three samples of different hardness. The samples were produced using Shamrock Elite Double 8, Zhermack Elite Double 16 (Zhermack Spa, Badia Polesine, Italy) and Silicon Mix SH A 12 Orange (ITALGESSI SRL, Castigliano, Italy) with nominal Shore A 8, 16 and 12 respectively. All the sample materials were mixed 1:1 in volume as suggested by the manufacturer and poured in a cylindric mold with a radius of 15 mm and an height of 15 mm. After pouring, the molds were placed in vacuum to avoid trapped air bubbles and left curing overnight at room temperature. The experimental setup was set as before, controlling the movement by means of a computer-controlled micrometric slide and measuring the output of the sensor with the above-mentioned digital multimeter. The probe was at first placed in contact with the sample under test (SUT). Then the measurement starts and the probe is pressed 1 mm towards the SUT and the actual displacement was measured. The position was maintained for 60 s to consider the elastic return of the material and then the probe was risen to its starting position. This test cycle was repeated three times.

### III. RESULTS

#### A. Device Characterization

The achieved results produced the calibration curve shown in fig. 2. The calibration test was performed without the tip, in the sense that the magnet was glued on a flat surface and while the sensor was moved with the micrometric slide, in this way it was possible to measure a wider range of the sensors, from 0, i.e. the contact between magnet and sensors, to "infinite", i.e. that distance above which the magnetic field variation generated by the relative movement of the magnet was no longer sensed by the sensor, in this case for a distance greater than 15 mm as shown in fig. 2 where it is evident a saturation plateau. As expected from the sensor specifications it presents a non-linear behaviour with saturation on both the measurement limits.

Regarding the tests performed on the silicone specimen, the probe was mounted as in fig. 1 (c), so the relative movement of the magnet and the sensor was limited to a 1 mm range. In the chosen configuration, the selected maximum distance is the one that provides a 0.1 V output bias to improve the sensitivity of the overall system to compression. The sensitivity of the achieved device is always negative and with a magnitude variable between  $-1.1 \cdot 10^{-3}$  V/ $\mu\text{m}$  and  $-5.1 \cdot 10^{-6}$  V/ $\mu\text{m}$ , as shown in fig. 3. Moreover, fig. 2 and fig. 3 show an

hysteresis in the measurements which is related to the magnetic field variation that is exploited for the displacement measurement. In order to overcome the problem, only compression experiments will be taken into account for the next evaluations.

Tests were than carried out to obtain the displacement-voltage characteristics shown in fig. 4.

#### B. Proof of Concept

The probe was tested with three samples with a Shore A hardness of 8, 12, and 16 and the results are provided in fig. 5. In fig. 5 (a) is evident the high repeatability of the tests, the mean variation from one repetition to another for the three SUTs is  $< 1\%$ . The diagrams show an overall difference in the three SUTs in terms of difference of voltage levels. In this configuration a relative hardness parameter  $h_{\%}$  could be defined as in equation (1), where  $d$  represents the applied displacement and  $d_m$  the measured one.

$$h_{\%} \stackrel{\text{def}}{=} \left(1 - \frac{d - d_m}{d}\right) \cdot 100 \quad (1)$$

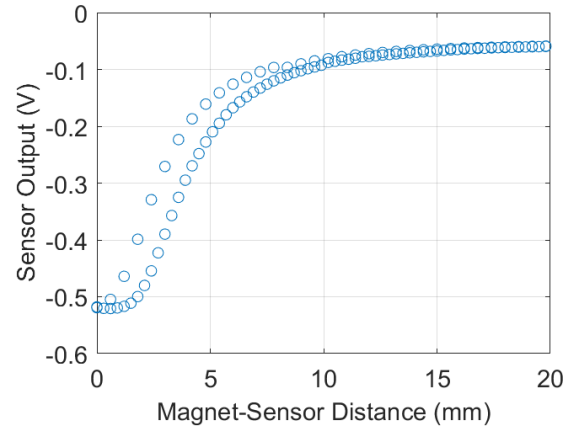


Fig. 2. Sensor calibration curve achieved with the selected magnet.

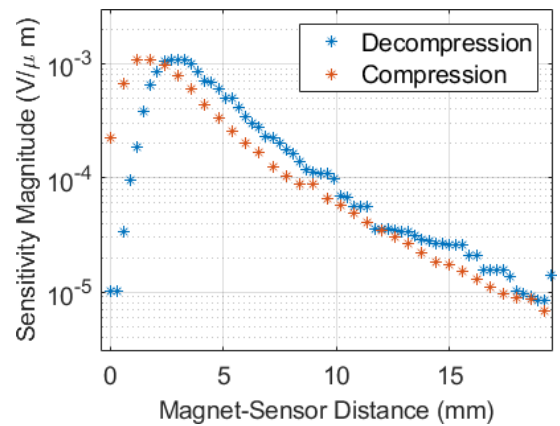


Fig. 3. Sensitivity of the device at different magnet-sensor distances.

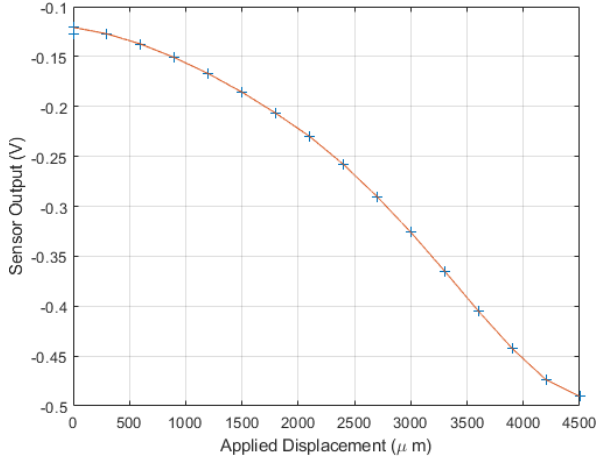
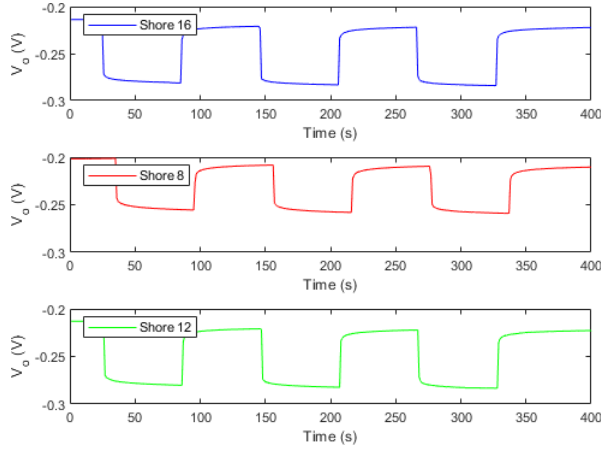
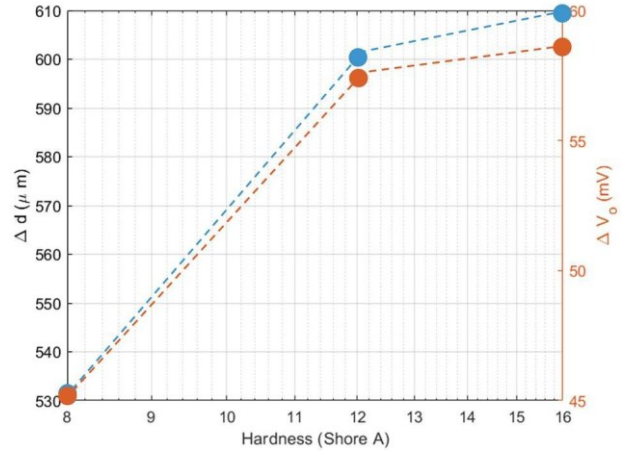


Fig. 4. Device calibration curve. The blue cross represents the experimental data, while the red line represents the linear interpolant used to better estimate the displacement.

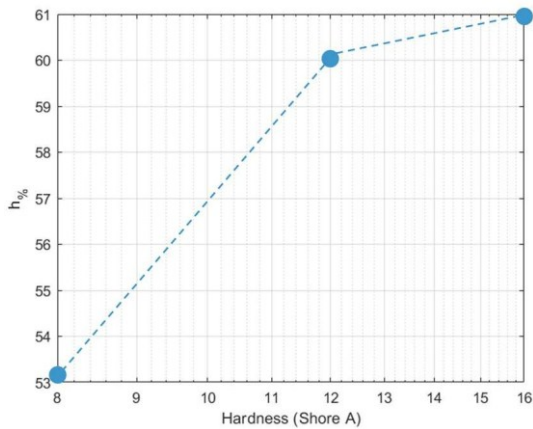
Those values are summarized in fig. 5 which reports the signals in time domain for three samples, fig. 5 (a), the calculated displacement and the difference of the output voltage of the probe, fig. 5 (b), the calculated  $h_{\%}$ , fig. 5 (c)



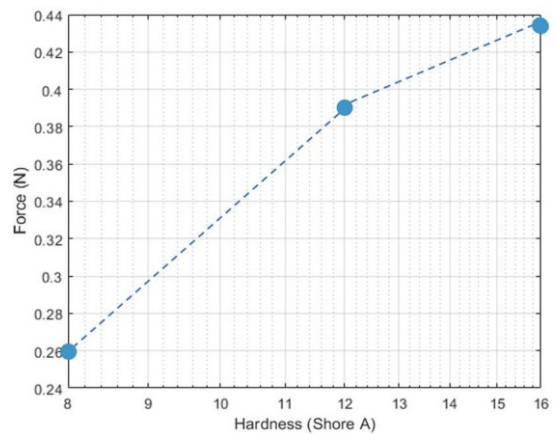
(a)



(b)



(c)



(d)

Fig. 5. Data acquired during the characterization. Signals in time domain for three samples with Shore 16, 8 and 12 (a). Calibration points in terms of the measured displacement and the output voltage of the sensor (b), the measured  $h_{\%}$  (c) and the force measured with the above mentioned force sensor (d).

and, as reference, the force applied by the indenter, fig. 5 (d). As expected, the achieved displacement resulted less than the applied one (1 mm) since the sample deformed and reduced it.

This parameter represents the relative hardness between the sample and the probing tip. In particular, a value close to 100% represents a material which it can be considered infinitely rigid to the tip penetration while, on the opposite, a value close to 0% represent a material significantly softer and deformable.

#### IV. CONCLUSIONS

The endoscopic endonasal transsphenoidal surgery has a steep learning curve and requires a certain level of dexterity and hand-eye coordination to surgeons. The strategy of the surgery changes according to the consistency of the pituitary adenoma, which is in most cases soft and, less frequently, hard. Obviously, surgeons need to be well trained for both scenarios. In the literature, the training solutions available to mimic the texture of PAs are mainly based on surgeons' experience gained in the field over the years. In this paper, it is proposed a novel and innovative sensorized probe capable to detect the hardness of soft material, by measuring

the variation of the magnetic field with a magneto resistive sensor generated by the displacement of a magnet glued to the tip. After an initial calibration of the probe, where it was possible to estimate the operating range in terms of distance of sensor and magnet, three materials with a slightly different hardness were measured. The materials are three silicones with an attested Shore A of 8, 12 and 16, and an indentation test in a displacement control condition was performed. The first results show an high repeatability of the tests with a mean variation for the three specimens < 1%. Future work will be conducted with an ex-vivo specimen of a pituitary adenoma in order to characterize its hardness with the defined parameter  $h_{90}$  to find the best substitute and also to define a first classification of the hardness of different pituitary adenomas.

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