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Bionics-based surgical training using 3D printed photopolymers and smart devices

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ABSTRACT

Additive manufacturing technologies support the realization of surgical training devices using, typically, photopolymers-based materials. Unfortunately, the material jetting family, able to print a large range of soft and hard polymers, requires expensive machines and materials, which are not always available. On the other hand, vat polymerization fails in the resolution/volume ratio and in the mechanical properties reconstruction. Stereolithographic 3D printers, mostly used in dental surgery, make possible to realize cheap and sustainable models for training activity using only one material, reducing the possibility to obtain different mechanical characteristics. Moreover, the printed objects have to be treated (i.e. curing post-processing) in order to obtain the required performances, that could be preserved for long term storing. The aim of the proposed approach is to assure the surgeons' skills improvement through bionic-based surgical 3D printed models and smart devices, able to reproduce the same perception of a real surgical activity. We demonstrated how it is possible develop smart devices capable to take into account the same characteristics of different materials (i.e. bone and spongy bone) even if stored for a long time.

Keywords: Bionics, surgical training, 3D printing, photopolymers, smart devices.

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1. INTRODUCTION

Surgeons improve their skills directly on patients because people are different and tissues properties are extremely difficult to reproduce synthetically[1,2]. In this context, 3D printing should support the surgical training activity[3,4] developing bionics[5] models extracted from the patient computer tomography[6–8]. Typically, the model fabrication requires some hours[9] and consequently is very difficult to schedule training courses without the previous realization of a dedicated set of trainers[8]. Then, the utilized materials[2,10] have to preserve the mechanical performance during storage time[11], in order to assure the same perception required to reproduce a real context[3,4], not always possible. The aim of the present study is to overcome these problems and reproduce the same perception during drilling using smart devices[12,13], in order to obtain the same applied drilling force on the compact bone via commercial medical grade photopolymerizable resin[14].

2. MATERIALS AND METHODS

2.1 Resin samples

We 3D printed a resin cube and eight samples to test the mechanical performance of autoclavable photo responsive medical grade resin (Figure 1). The printed object were stored in a paper box for 24 months, avoiding any direct interaction with light. The resin samples were 3D printed via stereolithography technology (Formlabs2, Formlabs, Massachusetts, USA) using Dental SG resin (Formlabs, Massachusetts, USA) for its high mechanical performance. Samples were then washed in isopropyl alcohol (GIP103, Girelli Alcool, Milano, IT) and cured under UV light (HybriLinker, UVP, Upland CA, USA) for 10 min for each face position. Finally, the mechanical performance were tested adopting Mach5 (MaCh3D SRL, Parma, IT) testing machine, following ISO 527 directive (Figure 1).

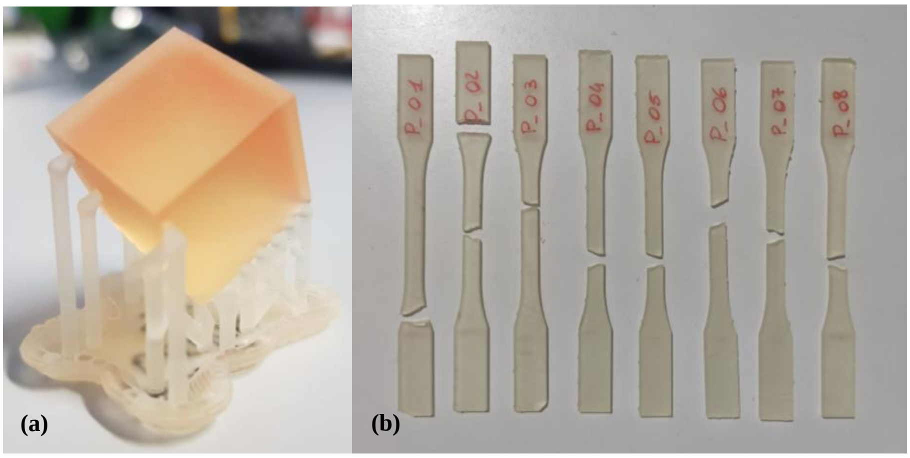


Figure 1. (a) 3D printed resin cube, (b) 3D printed resin samples.

2.2 Color detection

The color of the objects was analyzed adopting low-cost technology such as Raspberry Pi (Model B+ V1.2, Raspberry Pi Foundation, Cambridge, UK) with 5MP camera (Raspberry Pi Camera Rev 1.3, Raspberry Pi Foundation, Cambridge, UK). The resolution and the ability to detect the color components were validated using glucose DMEM w/o Phenol Red (Gibco®, ThermoFisher scientific, Waltham, MA, USA) for cell culture, modulating the acidity using hydrochloric acid.

2.3 Smart drill

The main parts of drill were 3D printed at 15mm/s using a custom made 3D printer (Bio-Foresti, UIMEI, Bergamo, IT) using PLA (3mm, Velleman Inc., Gavere, BE) with the hot-end and printing platform temperatures set at 191◦C and 50◦C, respectively. We used SolidWorks2015 (Solidsolution, London, UK) to design any printed part that were converted in machine language via a custom-made Slic3r open-source software.

We selected a commercial electric engine (Vmax=3V, Imax=1.33A, Engine Torque max=115g/cm) coupled with a commercial medical milling cutter. The linear displacement was managed using an extrusion kit (7350-3DCHOCO, Futura Group SRL, Gallarate, IT) with an hybrid stepper motor (nema 17, 17HS19-2004S1, torque: 5.9kg/cm).

2.4 Measuring instruments and statistics

The current was analysed with a pcb based on ACS712 Hall-effect-based linear current sensor (ALLEGRO microsystem, Manchester, USA), the number of resolution was detected using FC-03 sensor (Junye opto interrupter), while force was acquired using FSR 402 sensor (Interlink Electronics, California, USA). Force and current pcb sensors were characterised using industrial devices: PCE-FB Series (PCE Instruments, Lucca, IT) equipped with load cell (H3-C3-200kg-3B, Zemic Europe, Etten-Leur, NL) and multimeter (E2378A, Hewlett-Packard, California, USA). The software was implemented using Arduino SDK (1.8.5, Arduino, Monza, IT) and installed on ArduinoMega2560 Board (Arduino, Monza, IT). Data were analysed and plotted via Excel (Office365).

3. RESULTS AND DISCUSSION

The results (Figure 2, Table 1) demonstrated the long-term preservation of the flexural strength over 50MPa with a reduction of elastic modulus that overcome the 30%, related to the datasheet values provided from the producer. Moreover, the resin colour changed from orange to transparent/yellow showing the possibility to design a colour library useful to elaborate predictive algorithm.

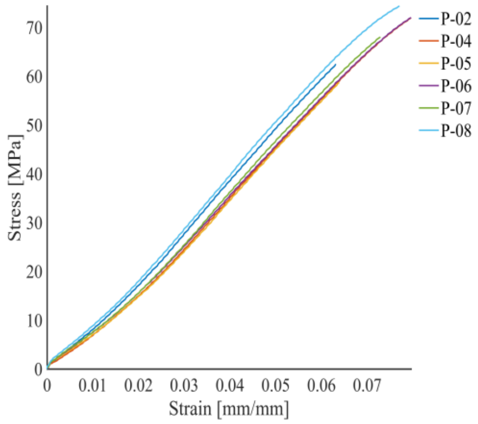


Figure 2. Stress-Strain curves of tested material after 24 months.

Table 1. Mechanical characteristics of 3D printed resin samples after 24 months.

Elastic Modulus	Linearity deviation stress	Maximum stress - Ultimate stress	Failure stress	Strain failure stress, %
E(MPa) = 1046,3±29,4	Rp(MPa) = 65,8±4,4	Smax(MPa) = 67,9±6,1	Rm(MPa) = 61,3±1,9	A(%) = 5,9±0,1

The color detection was entrasted to a commercial microcontroller (Figure 3) for digital analysis with real time sampling. After testing different types of commercial compatible cameras, we selected the Rasperry Pi Camera, that gives the possibility to extract image and not only to detect correctly the RGB. Then, we validated the related ability to detect a color change from red to transparent/yellow, colous ranges that are comparable with gum, bone and teeth colors (Table 2).

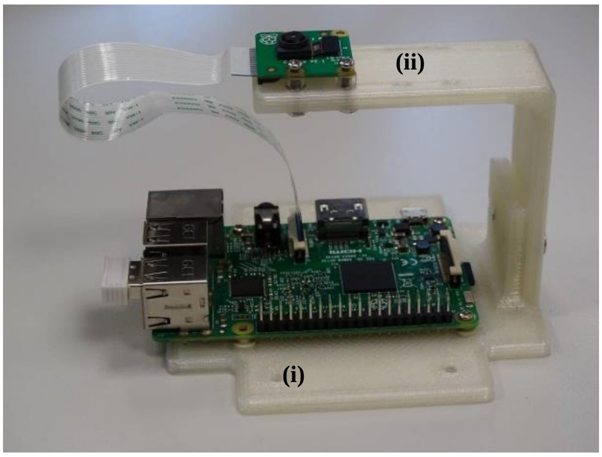
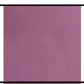
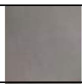
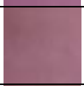
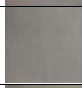
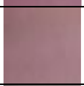
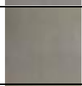
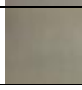


Figure 3. Colour detection platform. Raspberry Pi Model B+ V1.2 (i); Raspberry Pi Camera Rev 1.3 (ii).

Table 2. Colour-RGB data set.

Picture	Red	Green	Blue	pH	Picture	Red	Green	Blue	pH
	161	104	135	8.17		135	128	126	7.36
	160	111	128	7.97		139	135	130	7.13
	162	122	131	7.71		140	134	126	7.03
	143	131	131	7.48		144	139	122	6.83

Using a smart drill (Figure 4) equipped with pressure sensor, revolution number detector and amperometer we characterized the resin and bone analyzing force, power and gear shaft revolutions number, changing the linear displacement speed (5 speed evenly distributed). The resin cube analysis demonstrated a linear behaviour with R^2=0,97 (Figure 5a). The test on rat skull bone (8 skulls[15] and 5 speed for each skull) denoted a constant value of force between 3,4N and 3,2N (Figure 5b).

Finally, merging the color platform and the related functions we obtained a feedbacked system modulating the gear shaft revolution number and the related resistance force to achieve the same displacement typically obtained during drilling a bone. The presented method can be applied to every tissue, identifying the real force required for its drilling.

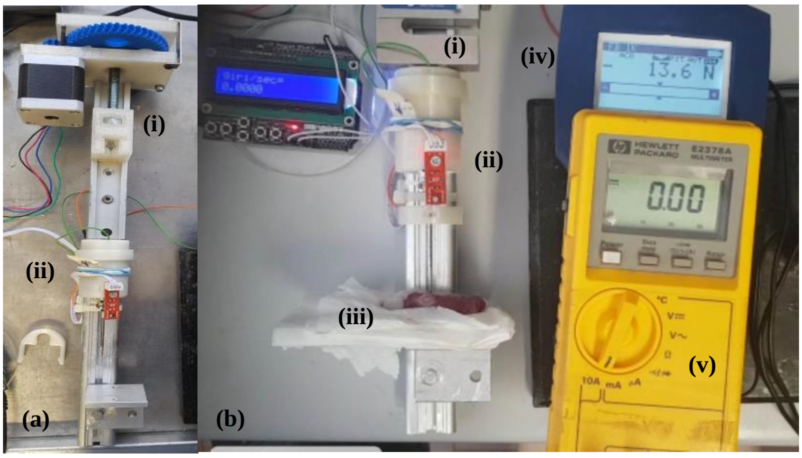


Figure 4. (a) Motion linear guide (i) and smart drill (ii); (b) Testing platform: load cell (i), smart drill (ii), rat skull (iii), force analyzer (iv), multimeter (v).

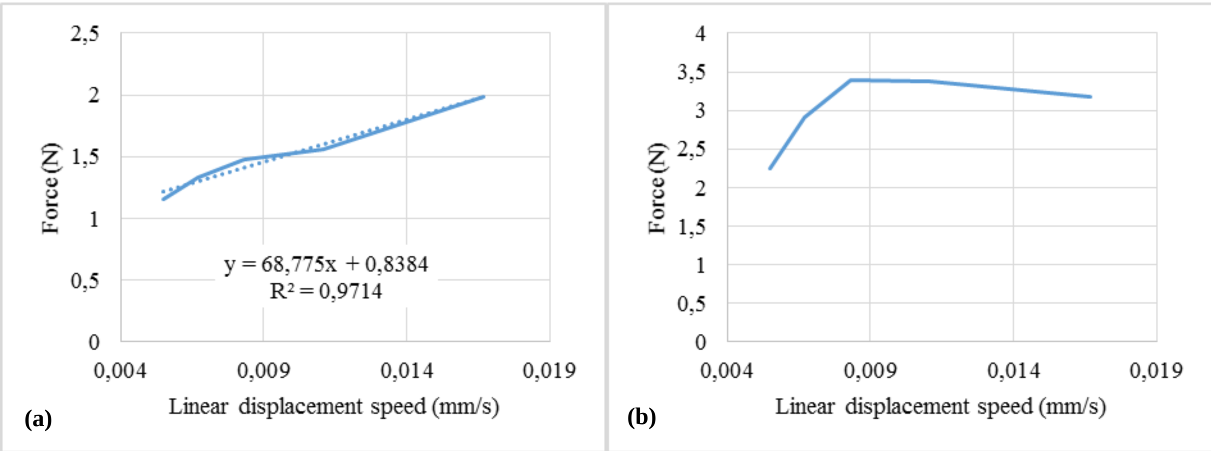


Figure 5. (a) Resin drilling force at different speed; (b) Skull drilling force at different speed.

4. CONCLUSION

We developed smart devices able to detect in real time the colors and the related functional shape perimeter and to manage the brake achieving the required perception values. In the smart devices real time management, using colors detection is mandatory to apply predictive algorithm. To implement the related training step we tested twenty-four months aged specimens and ex-vivo bones at different speed, evaluating force, current and number of engine revolutions during drilling. The photo sensible polymers demonstrated a color variation of the final object directly related to the mechanical performance useful to control the shelf life quality over the time.

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