BraceIO: Biosensing through Hydrogel Dental Ligatures

Eldy S. Lazaro Vasquez
University of California, Davis
Davis, USA
eslazaro@ucdavis.edu

Ali K. Yetisen
Imperial College London
London, UK
a.yetisen@imperial.ac.uk

Katia Vega
University of California, Davis
Davis, USA
kvega@ucdavis.edu

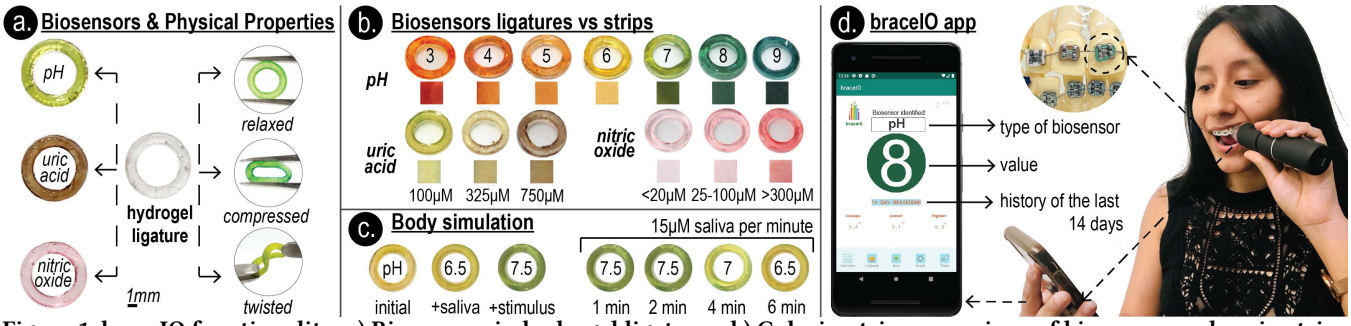

Figure 1: braceIO functionality: a) Biosensors in hydrogel ligatures. b) Colorimetric comparison of biosensors values in strips and ligatures: pH, uric acid, nitric oxide. c) Body simulation test for color reversibility. d) BraceIO app reading biosensor values.

ABSTRACT

Dental braces are a semi-permanent dental treatment that are in direct contact with our metabolism (saliva), food and liquids we ingest, and our environment while smiling or talking. This paper introduces braceIO, biochemical ligatures on dental braces that change colors depending on saliva concentration levels (pH, nitric oxide and acid uric), and can be read by an external device. This work presents our fabrication process of the ligatures and external device, and the technical evaluation of the absorption time, colorimetric measurement tests and the color map to the biosensor level in the app. This project aims to maintain the shape, wearability and aesthetics of traditional ligatures but with embedded biosensors. We propose a novel device that senses metabolism changes with a different biosensor ligature worn in each tooth to access multiple biodata and create seamless interactive devices.

CCS CONCEPTS

• **Human-centered computing**;

KEYWORDS

biosensor, biosensing, wearable technology, sensing device, braces

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1 INTRODUCTION

About 33% of the world's population has undergone orthodontic treatment at some point in their life. In the USA, 80% of the teenagers are currently under it [7]. Dental braces are comprised of brackets affixed to teeth and wires threaded through slots in the brackets [1]. The tiny rubber bands around the brackets are called ligatures. Their durability in the mouth, direct contact with saliva, colors customization and visibility are features that support our design of ligatures as a biosensing device. Saliva, as a carrier of information, provides a novel opportunity for biosensing. It is transparent with a complex composition, is in constant regeneration, and has direct connection with our metabolism. BraceIO proposes chemically sensitive hydrogel ligatures to detect levels of uric acid, pH, and nitric oxide in saliva through color change. These sensor could be use for kidney [3] and cardiovascular disease [8], metabolic syndrome [25], or chronic periodontitis [19, 21].

Several researchers created oral devices for sensing physiological data such as a smart brace that senses in vivo force/moment [10], an implant for oral activity recognition [15], or tongue-enabled computer wearables [12, 13, 28]. Moreover, biosensors are used as indicators when interacting with body biofluids such as biosensors temporal tattoos [4, 9], interstitial fluids by biosensors tattoos within the skin [27], saliva through a tooth tattoo for bacteria detection [16], or tears through contact lenses with biosensors in microfluidics [18]. Wearable biosensors for saliva varies in both the form of the device and the salivary composite. Cavitas Biosensors [17] is a mouthguard for glucose sensing and "wearable lab on body" senses physiological and biological fluid data using a device on the cheek [20] that has a scanner for glucose analysis [24], and an intraoral device adhered to the palate to measure sodium intake [14]. Due to the discomfort of devices around the mouth, their maintenance and the visibility of electronics, this research aims to design biochemical brace's ligatures that keep their physical and aesthetic features and extend their traditional functionality to sense biodata. We used an external device that connects to an smartphone

for data analysis. Moreover, braceIO could incorporate a different biosensor in every tooth in order to sense several biodata.

2 IMPLEMENTATION

2.1 Biosensor Brace Ligatures

The implementation includes the production of pre-hydrogel solutions, fabrication of hydrogel rounded ligatures, and the process to prepare biosensor solutions to apply to the ligatures. **a) Hydrogel.** The monomer solution consisted of acrylamide (3.2 g), PEGDA (1.5 g), 2-HMP (5 µL), and deionized water (1 mL). This concentration allows the material to have malleable physical properties similar to a conventional elastic ligature. The mixture was evenly stirred and warmed up at the end with a heat gun to dissolve the acrylamide in the solution. While the solution was still warm, it was poured in the ligature silicone molds. **b) Molding.** The ligatures have 7mm of diameter and 1mm of thickness. Negative molds are created in resin using a stereolithography 3D printer for a fine resolution and positive molds are made with silicone [23] with a curing time of one hour. A thin layer of Vaseline was spread inside the molds before injecting the hydrogel. Then, they are cured for 15 min under UV light (Fig.2a). **c) Biosensor.** We used chromogenic pH, nitric oxide and uric acid sensitive biosensors to obtain quantitative colorimetric measurements of aqueous solutions with different values. The biosensors (15 µL) were added to hydrogel ligatures that were previously resting in DI water to simulate the mouth environment.

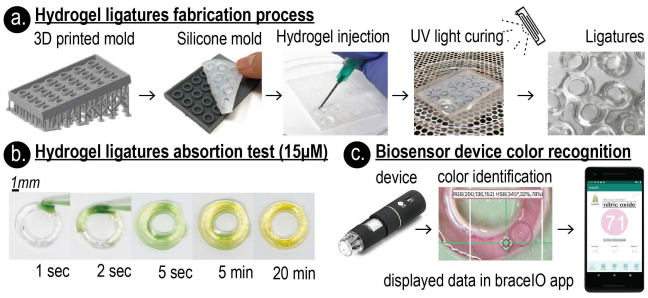

Figure 2: Implementation: a)fabrication process, b)biosensor absorption, c)color recognition through braceIO.

2.2 Biosensor Device

The biosensor device uses a portable wireless microscope to capture an image of the ligature on the braces and an app identifies the biosensor through that image's color (Fig. 1d). The device has a 2MP HD CMOS sensor and a 50X-1000X magnification [26]. The images were taken at a 50X magnification with no built in light source in our tests, however the device has light source that could be adjusted to improve imaging. The user approximates 3cm the lens of the microscope to the ligature and capture the image while observing it on the smartphone. braceIO app identifies the HSB and sRGB data from the image (Fig. 2c) and converts the mean of the RGB colors to CIE color space (CIE 1931). It maps that value to the closest value on manufacture's biosensors reading chart (CIEDE2000). The user can select the type of biosensor to read before they make the image capture. The app displays the current reading, the last 14-days data (lowest, highest, average), and a history graph of biosensor levels readings for self feedback or sharing.

3 TECHNICAL EVALUATION

Ligatures absorption time. The hydrogel ligatures need at least 8 µL of biosensor solution to cover the ligature volume. However, 15 µL was found to be an optimal volume of biosensor per ligature to allow better color changes. It takes up to 20 min for a total solution absorption before using the ligatures in our study (Fig.2b). **Ligatures testing results.** The hydrogel ligatures takes from 1-2 min to show results (Fig. 1c) unlike the manufacturers' biosensor strips which allow test reading at 30s-1min. The ligatures created have appropriate response to compression, bending and torsion forces (Fig. 1a). **Device color testing results.** In order to validate the biosensor level identification, the biosensor ligatures and strips were compared after applying to both the same amount of stimuli (Fig. 1b). The ligature had a ±4 hue value variation from the strip. The sensor range between 0-360. The reversibility was visible and with similar sensing results until 4 iterations. **Body simulation.** We tested the colorimetric reversibility under real salivary flow rate after stimulation, by adding 15 µL saliva every minute [11]. The ligature changed its colorimetric value after 2 minutes of being exposed to the stimulus. It took 6 minutes for the ligature to change its value completely to the user's mouth pH (Fig. 1c). We performed the test 3 times obtaining same changes and values.

4 CONCLUSIONS AND FUTURE WORK

We present braceIO, biochemical brace's ligatures as a salivary analysis display that could be read by a device and wirelessly send the data to an app. Our contributions include: **1) Ligatures Form Factor.** The design rationale for exploring ligatures consists in their traditional features: direct contact with saliva, colors selection, duration in the mouth and visibility. They were fabricated from an acrylamide-co-PEGDA hydrogel that required moisture provided by the oral cavity and saliva environment. They were created keeping their physical properties: flexibility, shape, size, colors. **2) Multiple biosensors, one sensing device.** This project proposed biosensing through different biosensors located in each tooth. braceIO identifies the biosensor selected by the user in the app without changing the device hardware. Due to several illnesses require monitoring more than one biodata, the user could select the biosensors needed and wear those ligatures. **3) Potential Applications.** It could be use for health monitoring including cancer and cardiovascular disease with uric acid biosensor [22], dental health, eating disorders in bulimic patients [2] and pharmacokinetics investigation [29] with pH biosensor, and heart failure and pulmonary hypertension with nitric oxide biosensor [5]. Other biosensors could be embed into the ligatures to several sensing possibilities: glucose biosensors [24], bacteria for dental health, environment interactions, drug consumption, virus and hormonal changes. Future work will conduct tests with subjects, and on biocompatibility, reversibility, durability, food staining [6], stretchability, bendability of the ligatures. Future discussions will involve privacy issues and data analysis. New applications could develop biosensors to act also as actuators such as for flavour or drug delivery.

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