The First Drinking Simulator Unit

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Abstract

Introduction: Current Thermal cycling units fail to simulate the drinking behaviors, and oral balancing temperature. They cannot also simulate other oral conditions such as drink coloring, and chemicals like tea, coffee, carbonated and noncarbonated, citrus juices as well as alcoholic and nonalcoholic drinks and also saliva and milk itself. The main objective of this study is to introduce the designing and manufacturing the first Drinking Simulator Unit (DSU) that reproduces the thermal, color and chemicalcycling as well as the drinking behavior and oral temperature in lab conditions uniquely. **Methods:** The invented system generally has two parts: the hardware and the software parts. The hardware consists of the mechanical and electronic parts. The software part is responsible for controlling the heating and cooling systems, electric valves, the pumps, and automatic filling systems of tanks as well as the sensors of the machine. **Results:** DSU is the first unit can reproduce the thermal, color and chemical cycling as well as the drinking behavior and oral temperature in lab conditions. Different kinds of colored and acidic drinks and also other chemical materials such as bleaching substances as well as detergents and antiseptics used for dentistry, industrial and medical purposes can be tested by DSU. DSU has also to be considered as an appliance performing *in-vitro* researches on dental structures. C**onclusion:** The invented system can greatly improve and validate the results of such researches.

Key words: Chemical cycling, color cycling, dentistry, drinking, simulator, thermal cycling.

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Introduction

Dentistry relies heavily on materials and techniques. They play an important role in the success or failure of the restorative treatments. The materials and techniques must be initially tested in laboratory and then in clinical conditions. On the one hand, *in-vivo* research is time-consuming, costly and sometimes impossible. On the other hand, owing to ethical considerations, procuring enough samples is difficult and even at times impossible and that is why, most of the studies on materials and techniques are conducted in- vitro today.

Since tooth structures and restorative materials have different coefficients of thermal expansion, cold and hot drinks or foods exert different degrees of contraction and expansion in the tooth structure and dental filling materials which may finally end up debonding and microleakage (1-8). Thermal cycling is one of the most widely used procedures to simulate the physiological aging experienced by biomaterials in clinical practice. Consequently, it is routinely employed in experimental studies to evaluate materials' performance (9). Therefore, one of the most important characteristic features of the oral cavity which has a great impact on the function of dental materials is the thermal changes resulting from consuming drinks and foods with different temperatures.

In order for applying thermal changes to *in-vitro* studies, Thermal Cycling Units (TCU) have been used since the 1950s. The popular methods of thermal cycling are primitive in which only two water baths in rapid succession are used. The baths temperatures are mostly 5•C for cold , and 55•C for hot provocations (9, 10).Despite its popularity in dental research, the traditional methods even fail to simulate and imitate the natural thermal changes of oral environment. They also fail to consider the oral balancing temperature, and simulation of the natural time, drinking patterns and behaviors. TCU also fail to test other drinks (e.g. colored and chemical ones) in lab conditions.

On the other hand, it is obvious that close simulation of the oral cavity condition is a necessity in developing the techniques and producing the materials. In conducting most of the laboratory research, the materials, techniques and dental structures should be tested by the shock patterns they may exactly receive in the oral cavity. The shocks can be exerted not only because of temperature, but also because of chewing pressures, special eating or drinking habits, chemical elements (e.g. acidic, citrus juices, basic, alcoholic, non-alcoholic and carbonated/ noncarbonated drinks) as well as colored substances (e.g. tea, coffee and colored juices). Saliva and dairy drinks related tests cannot be imagine to do with TCUs (9).

Besides, the oral balance temperature allows the stress exerted as a result of drinking liquids and eating foods of different temperatures to be released without being accumulated in the material. This prevents the material from getting fatigued sooner than what we witness in using traditional thermal cycling units with 5•C and 55•C baths. An exhaustive most recent literature search, examined the effect of thermal cycling on restorative dental materials, was performed with electronic database and by hand. The search was restricted to studies published from 1998 to August 2013. No language restrictions were applied. The search identified 193 relevant experimental studies. The majority of studies used their own procedures, showing only a certain consistency within the temperature parameter (5-55°C) and a great variability in the number of cycles and dwell time chosen. A wide variation in thermal cycling parameters, applied in experimental studies, has been identified. The comparison of results, amongst studies seemed to be impossible. The available data suggest that further investigations will be required to ultimately develop a standardized thermal cycling protocol (9).

So, the main purpose of this paper is to introduce the Idea and designing of the first invented drinking simulator to imitate not only the thermal conditions more accurately, but also the color and chemical as well as the natural drinking behavior in lab conditions for testing on dental materials, techniques and dental structures.

Materials and Methods

To achieve the goals set above, DSU consists of two parts: the hardware including the mechanical and electronic sections of the system and the software consisting of the program codes.

The system is composed of three tanks containing a liquid (water or other drinking or testing liquids) whose temperature can be changed by heating or cooling units installed around each tank.

One tank is equipped with a chilling system in order to prepare the liquids for temperatures between 0-10$^{\bullet C}$. The other two tanks have heating systems for preparing liquids ranging in temperature between 32-42$^{\bullet C}$ and 50-60$^{\bullet C}$, respectively. The temperature is adjustable. In addition to the default temperatures (5, 37, 55 $^{\bullet C}$), it can provide a wide range of thermal conditions if need be (Figs. 1-3).

The system (DS) has a series of showering or testing chambers. These chambers are used for showering the liquids onto the samples in continuous (CON-) or pulse (INT-) modes by square showerheads in order to imitate natural drinking behavior. The samples can also be immersed (IM-) into the liquids (Table 1 and Figs. 1-3).

Table 1. Different possible default programs for drinking simulation and thermal-chemical-color cycling tests with DSU

Drinking Simulator default programs	Tank-1 5^{oc} /Seconds	Tank-2 37^{oc} /Seconds	Tank-3 55^{oc} /Seconds	Time of each cycles	Number of cycles/ Year(s)	Immersion	Showering Modes /immersion	Mode Codes
DS/CON-1825	+ /30s	+ /30s	+ /30s	90 s	1825/1	_	Continuous	1
DS/CON-3650	+ /30s	+ /30s	+ /30s	90 s	3650/2	_	Continuous	2
DS/CON-5475	+ /30s	+ /30s	+ /30s	90 s	5475/2.5	_	Continuous	3
DS/CON-7300	+ /30s	+ /30s	+ /30s	90 s	7300/3	_	Continuous	4
DS/INT-1825	+ 6x5s with 5s interval	+ /30s	+ 6x5s with 5s interval	140s	1825/1	_	Intermittent	5
DS/INT-3650	+ 6x5s with 5s interval	+ /30s	+ 6x5s with 5s interval	140s	3650/2	_	Intermittent	6
DS/INT-5475	+ 6x5s with 5s interval	+ /30s	+ 6x5s with 5s interval	140s	5475/2.5	_	Intermittent	7
DS/INT-7300	+ 6x5s with 5s interval	+ /30s	+ 6x5s with 5s interval	140s	7300/3	_	Intermittent	8
DS/IM-1825	+ /30s	+ /30s	+ /30s	90s	1825/1	+	Immersion	9
DS/IM-3650	+ /30s	+ /30s	+ /30s	90s	3650/2	+	Immersion	10
DS/IM-5475	+ /30s	+ /30s	+ /30s	90s	5475/2.5	+	Immersion	11
DS/IM-7300	+ /30s	+ /30s	+ /30s	90s	7300/3	+	Immersion	12
Optional	$2\text{-}10^{oc}$	$32\text{-}42^{oc}$	$50\text{-}60^{oc}$	Optional	Optional	Optional	Optional	13

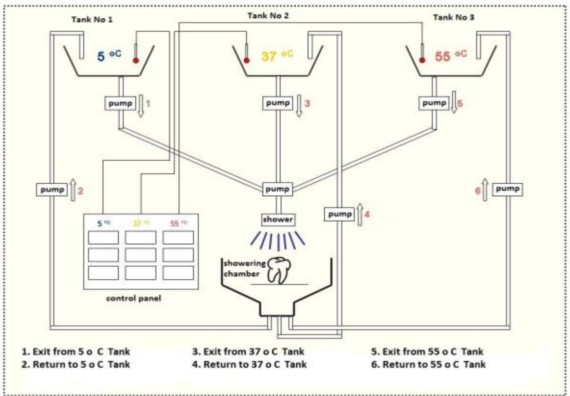

Figure 1. Designing the initial plan of the DSU

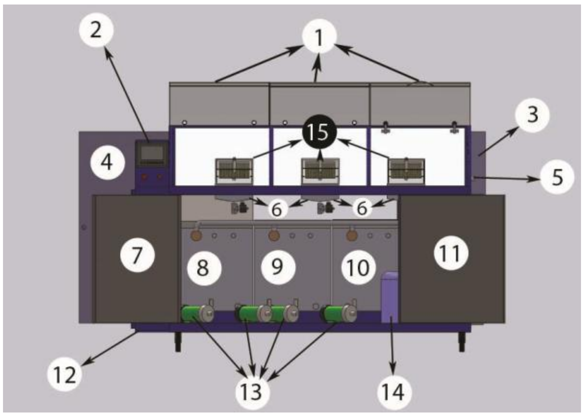

Figure 2. Front view of the DSU

1-Glass lids covering the immersion and showering chambers (Opened)
2- HMI and Control Panel (Control Panel)
3- Rear door
4- Rear door
5- Connections to the Load cycler and input tap water
6- Underneath view of the triple immersion and showering chambers and the collectors and electric valves
7- Front door
8-Tank no. 3 for liquid storage
9-Tank no. 2 for liquid storage
10- Tank no. 1 for liquid storage
11- Front door
12- Electric panel
13- Four Teflon –coated pumps
14- Compressor (chilling unit)
15- Lids of 3 Immersion and showering or testing chambers (with shower heads and immersion sensors)

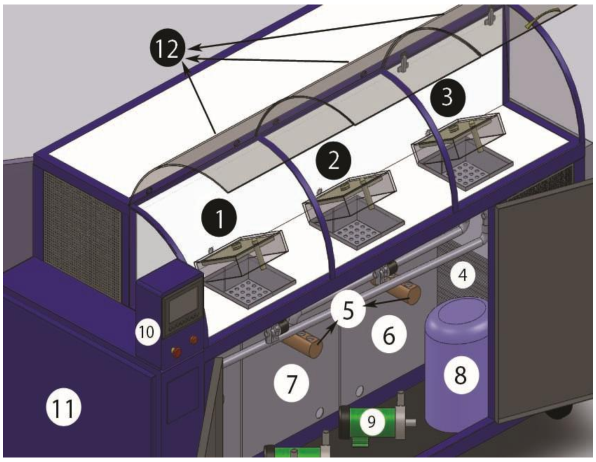

Figure 3. Side view of the DSU

1- Immersion and showering or testing chambers no. 1
2-Immersion and showering or testing chambers no. 2
3- Immersion and showering or testing chambers no. 3
4- Condenser (chilling unit)
5- Collectors and electric valves under 3 immersion and showering chambers
6- Liquid storage tank 1
7- Liquid storage tank 2
8- Compressor (chilling unit)
9- Teflon-covered pump
10-HMI and control panel (Control Panel)
11-Electric panel
12- Lids covering the immersion and showering chambers

The system has four Teflon-coated pumps to circulate the liquids through conduits and pumps the liquids to three showering/testing chambers.

Thirty-two electric valves have been installed to control the flow of the liquid to and from the storage tanks to and from the showering/immersion chambers.

The tanks, chambers and liquid conduits are insulated to prevent any thermal exchange in these parts (Figs 1-3). Furthermore, they are all made of corrosion-resistant steel (SS 304). Pumps are coated with Teflon; therefore, DSU can also use different acidic, basic and color liquids that can be found in different food diets for different research purposes. This also includes coffee, tea, various brewing drinks, sherbets, fruit juices as well as alcoholic and non-alcoholic drinks. On the whole, the DSU allows the cycling of colored and chemical drinks.

The invented machine can be connected to other lab equipment such as artificial tooth brush machine and Load cycler to perform load and thermal or color or chemical cycling simultaneously which enables four operators to work with different thermal cycling programs at the same time using up to three showering chambers as well as other attached equipment.

The system is also equipped with a water treatment unit and can directly be attached to tap water to refill the tanks automatically. The outgoing water of the showering chambers is also passed through special filters to eliminate possible impurities and particles.

The electric panel includes Programmable Logical Controller (PLC) to control the operation of the system.

The system also outfits with a color finger touch Human Machine Interface (HMI) to show the operation of different parts of the system (Figs. 2 and 3) to enable different operators to input data and make the required adjustments.

PLC controls all different mechanical and electronic parts of the system.

The software system is programmed to have certain default options for exerting thermal or other cycles. The defaults include the following factors: showering pattern (pulse or continuous modes of showering which imitates the frequent or non-stop modes of drinking), time for each cycle and number of all cycles. Like traditional TCU, the system also allows the samples to be immersed into the liquid in the showering chambers.

The software also enables the operator to choose and adjust the specific features of the cycle. The controlling software system provides a chance for the operator to control which liquid, from which tank, at what temperature, for how long, with which sequence and pattern is to be showered on the samples in each chamber which is similar to drinking behavior (Table1 and Figs 1-3). To do so, the system is equipped with a color finger touch HMI.

In case of any mechanical failure in any part of the system, the software can give audio/visual signal and make the whole system stop functioning.

Discussion

An in-vivo pilot study was done to record variations in temperature at various sites in a subject's mouth in response to a standardized thermal challenge and to determine a more realistic thermocycling regimen for future use. A maximum of 68.0 degrees C and a minimum of 15.4 degrees C were recorded. Most commonly used thermocycling regimens are clinically unrealistic, and temperatures vary widely throughout the mouth when hot or cold drinks are taken (11).

On the other hand, in normal conditions, after a sip of drink the teeth and dental materials come into contact with the passing liquid. Then saliva with normal oral temperature surrounds them again. The balancing temperature allows the stress exerted as a result of drinking liquids of different temperatures to be released without being accumulated in the material. This prevents the material from getting fatigued sooner than expected. However, this may not happen as a result of placing the samples in two different thermal baths of $5^{\bullet C}$ and $55^{\bullet C}$ in rapid and sudden succession in traditional thermal cycling units.

In other words, mechanical, chemical and thermal features of dental materials as well as the structure of the teeth can be greatly influenced by the various frequent thermal, chemical and color changes in the mouth. Exact simulation of such changes in in-vitro studies is a must which is impossible to be performed with current and traditional thermal cycling units.

The most important problem with the available or traditional thermal cycling units is that they fail to exactly imitate the oral condition. In these units, the samples are suddenly immersed in two water environments of $5^{\bullet C}$ and $55^{\bullet C}$ usually for a certain extent of time without considering the natural drinking behavior and especially oral balancing temperature. This also fails to imitate and simulate the natural time and drinking patterns (i.e., liquid flow and showering) as we witness in real in-vivo oral conditions. As mentioned, another shortcoming in the previous models is that they fail to simulate the balance temperature of the oral condition (i.e. $37^{\bullet C}$) which is the intermediary condition between the two extremes of thermal shocks resulting from drinking or eating cold and hot drinks and foods. The traditional thermal cycling units cannot also simulate other conditions such as drinking acidic, basic, colored, and carbonated as well as alcoholic and nonalcoholic drinks.

Among the characteristic features of the innovation in DSU, one can refer to the more similar and accurate simulation of thermal cycling by considering a balancing temperature of 37•C between two usual thermal shocks (5•C -55•C).

To imitate the drinking behavior, DSU can shower the liquid in continuous or pulse modes depending on the mode of simulation the operator wants from 1 to 15 sips with 2-10 seconds interval and 30 to 2 seconds sipping time respectively.

All mechanical parts are designed in such a way that enables the system to use all different acidic, basic and colored drinks and liquids that can be found in different food diets and cultures. Such drinks include dairy-based and carbonated ones, coffee, tea, various brewing drinks, sherbets, fruit juices, alcoholic and non-alcoholic drinks.

The ability to use different closed systems of chemical cycles in order to do chemical durability tests of dental materials and tooth structure with water or artificial saliva related tests makes DSU a unique device. Other potential dentistry applications include testing the effect of different detergent, bleaching and disinfecting substances on medical and dental equipment .DSU can also be used to disinfect the equipment and extracted teeth. Among industrial usages of DSU one can refer to examining the effects of different colored liquids, drinks, acids, bases, detergent, bleaching and disinfecting substances on clothing, surfaces and cutlery and crockery. Furthermore, DSU can be used to test the effect of acidic rain on external building materials thanks to the resistance of the system against chemical and corrosive substances. There is relatively no limitation for number, size and weight of samples in this unit. All the operations of the new system are controlled by PLC which gives it a unique ability to simulate the frequency and continuity of the drinking behavior. This is for the first time that such a unit is provided with software enabling the operator to choose and adjust the specific and optional features of the cycle through HMI. DSU is equipped with a water treatment unit attached to tap water. This renders the manual refilling of the tanks unnecessary and the system can work automatically for a long time.

Another unique feature of DSU is its ability to be attached to other lab equipment such as load cycler and artificial toothbrush units which allows the operators to work with different cycling programs and different thermal, chemical and color shocks simultaneously.

Results and Conclusions

DSU is the first system in the history of dental research to simulate the drinking behavior and conditions in order to imitate more closely the oral environment in *in-vitro* experiments on dental materials, techniques and tooth structure.

On the whole, DSUcan be used to closely imitate the oral cavity condition in terms of exerting not only improved and more similar thermal cycling to the real oral cavity behavior, but also chemical and color cycling and shocks with acidic, basic, alcoholic, non-alcoholic and carbonated and noncarbonated drinks as well as colored drink such as tea, coffee, red wine, and various brewing drinks, sherbets, colored - citrus fruit juices and also saliva, milk and other dairy-based drinks itself to carry out *in-vitro* experiments on dental materials, techniques and structuresin different fields of dental research such as operative dentistry, dental materials, prosthodontics, orthodontics, pediatric and implant dentistry.

The system is the first of its type for exerting chemical and color shocks in dental research. On the other hand, DSU is a unique device that can use artificial saliva in the process of thermal-chemical and color cycling as well as in a closed circle in chemical stability tests. Besides, the new system also allows the researchers to test different color liquids, drinks, acids, bases as well as detergents and bleaching substances used in industry. To the best of our knowledge, this can be done for the first time in the field of dental research.

Greater success in simulating oral conditions in dental research means more reliability in the results and greater certainty in applying these results to clinical conditions.

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The inventors would deeply like to dedicate this invention to the 12th Imam of Shiite of Islam (ATFS).

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