Design and Development of 3D Printed Dental Drill Guide for Better Flow of Irrigant at Drilling Site

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Abstract. The aim of this study was to design and fabricate a dental drill guide with built-in external irrigation mechanism for improved flow of irrigant at the drilling site to restrict the bone temperature below the threshold of thermal necrosis i.e. 47 °C during implant site preparation. This guide was compared with the conventional type 3D printed drill guide (commercially available in the market) in terms of heat generated while drilling. Temperature was measured with K type thermocouple and data acquisition system using PPMA as a work piece instead of bone. Constant drilling load of 1.7 Kg was applied using a dedicated experimental setup. Drill speed was kept constant at 1200 rpm throughout the experimentation. Temperature was measured at the depths of 3, 7 and 11 mm with the help of thermocouples placed perpendicular to the drill axis. Incremental drilling as prescribed the drill manufacturer was performed. More than 10% improvement in maximum temperature was recorded at all the drilling locations when new drill guide was used.

1. Introduction
In spite of noticeable developments in treatment and precaution of oral care, lots of teeth are lost. Males and females of various age groups are self conscious regarding their dentures, bridges or missing tooth. Many experience difficulty in talking as their dentures slip or click. Moreover, they feel aged before time due to tooth loss [1]. Attitude of people regarding tooth loss has begun to change [2]. Aesthetic instead of operational factors determines an individual’s requirement about replacement of lost tooth. The need for the replacement is highly associated with the location of the lost tooth [3].

A variety of alternatives like bridges, dentures and dental implants are available for the replacement of missing teeth but the latest of them are dental implants [1] Dental implants fix in a jaw bone. So, they function more like a natural tooth and becomes ideal choice for the replacement of lost teeth. Moreover, dental implants integrate with the jawbone and help in preventing bone loss. Dental implants provide an outstanding substitute to the disadvantages of traditional dentures and bridges.

The primary reason for the success of dental implant is the biocompatibility of titanium, due to which it bonds to the bone by the process of osseointegration. Biocompatibility is basically acceptance of an...
artificial implant by the adjacent tissues as well as by the body in total. Therefore, biocompatibility becomes an essential requirement for the implant along with other functional requirements [4]. Titanium and its alloys are well acceptable by the body and it also meets the other functional requirements.

In cases of a tooth loss in a patient, having limited bone to support the implant and due to adjacent anatomical structures drilling has to be performed very carefully, preferably with help of dental drill guides. These guides have improved patient care by allowing implant placement in areas that may have required grafting and additional surgeries. Drill guides acts a navigator and help surgeons to place implants more accurately and clearly [5]. Metallic sleeves inside the 3D printed template facilitate the surgical procedure by guiding the drill to the exact location and orientation as determined in the software. Drill guide needs to fit perfectly on the mating surface of the jaw because of the complicated shape of the bone. Surgical guides can be manufactured using 3D printing techniques like stereolithography, polyjet or FDM and are custom manufactured for each patient [6].

Bone temperature is considered the most vital parameter while performing dental surgery and it must be maintained below the starting temperature of necrosis, i.e. 47°C. Thermal conductivity of cortical bone is 0.16–0.34w/m/k and that of cancellous bone is 0.30w/m/k, this implies that the heat produced while drilling is preserved at the cortical portion the bone. Taking into consideration the lower thermal conductivity of bone, drilling could cause a cumulative heat increase, particularly in the cortical bone. That’s why, the cavity needs to be irrigated regularly throughout drilling process. Irrigation can be external or internal. External irrigation seems to be more efficacious in comparison to internal irrigation because firstly, in internal irrigation there are chances of clogging of holes provided for irrigation in the drill bit due to bone chips. Secondly, the cortical bone is tougher and has higher coefficient of friction than the cancellous bone. It experience frictional forces for a longer period of time compared to the deeper regions of the cavity [7].

Conventional dental drill guides have a drawback of rise in bone temperature. These guides must fit and adapt perfectly in order to achieve accuracy of implant placement and this can prevent adequate irrigant from reaching the osteotomy site which increases the temperature above 47°C. It further results in problems like bone cell death, longer healing time and even failure of implants. Therefore, it becomes extremely important to design and develop dental drill guides which are not only accurate but also provides adequate irrigation at drilling site.

2. Material and Methods

2.1. The Design
Existing dental drill guides rely on manual external cooling via syringe or tubes attached to the hand piece. Therefore, in this study, an attempt has been made to design and develop a dental drill guide having improved external irrigation system as inbuilt feature to eliminate the negative aspect of existing dental drill guide.

A dental drill guide basically comprises of two components: sleeves/ bushes (which act as a guiding cylinder) and the contact surface or template (Fig. 1). Sleeves are generally made from surgical grade stainless steel whereas templates are fabricated by different 3D printing techniques.
The objectives of this research work are as follows:
- Better circulation of irrigant to the control bone temperature
- Precise fitment of guide over the jaw
- Accuracy of drilled holes
- Easily adaptable by the surgeons
- Easy to fabricate

2.1.1. Design and Development of Template. Template is 3D printed part which adapts the bone or the tissue of the patient depending upon the type of guide. In this case bone supporting guide have been created. Therefore, it has to adapt very precisely above the jaw bone.

Mimics Innovation Suite (MIS) was used for designing. It is an image processing software commonly used for studying human anatomy and designing custom specific biomedical equipments (like guides).

Designing process involves segmentation and 3D model creation of mandibles in Mimics followed by virtual implant placement and template design in 3-matic. After designing, the template was 3D printed on Eden 260V (a polyjet technology based 3D printing machine by Stratasys).

2.1.2. Designing and Development of Bush / Sleeve. To increase the circulation of irrigant at the drilling site for controlling the bone temperature, irrigation channels were provided in the internal diameter of bush through grooves. The supply of irrigant to these irrigation channels is through inlet pipes brazed in the transverse direction of the bush (Fig. 2). In this new method of irrigation, fluid flow is from two directions which improve the fluid flow for cooling and removal of bone debris / chips where as in the conventional design these bushes do not have any such irrigation channels and fluid flow may get restricted.
2.2. Evaluation
In order to evaluate the new design in terms of rise in bone temperature while executing dental implant surgery, comparative in-vitro experimentation was performed. With the intention to execute the trials in an affordable manner and to nail down impact of homogeneity and anisotropy of bone on the results, polymethylmethacrylate (PMMA/Acrylic) was chosen for the experimentation over the bovine bone. PMMA is a homogeneous and isotropic material with properties near to that of bone, particularly the thermal conductivity. Thermal conductivity (W/mK), specific heat (J/kg K), density (kg/m³) and thermal diffusivity (m²/s) of (bovine cortical bone, femur/PMMA) are 0.54/0.50, 1260/1297.9, 1800/1683, 2.38x10⁻⁷/2.29x10⁻⁷ respectively [8].

2.2.1. Experimental Apparatus. With a purpose to effectively evaluate the performance of newly designed guide, it was required to control drilling parameters like rpm, feed, coolant flow rate, torque and pressure / load on the hand piece etc. Almost all the listed variables can be controlled except drilling pressure because it depends upon the surgeon and it may vary as the surgical procedure continues. Therefore, a dedicated system was created to carry out the testing (Fig. 3). With the aid of this system it was possible to control the pressure.
Temperature changes during the drilling sequence were assessed with K type thermocouple having 2 mm tip diameter, 2 m long and temperature range from 0 °C to 482 °C. To record the temperature at different locations, three thermocouples were placed in the wells made in the work piece. Thermocouples were connected to the National Instrument’s data acquisition system (NI 9214), it is a 16 channel thermocouple module having sampling rate of 68 samples per second. This DAQ was further connected to a computer having Labview software. Data received from the thermocouples was digitized and saved in the computer after processing through data acquisition system and Labview software.
2.2.2. Sample Preparation and Experimentation. Pieces of 40 mm length were sliced from acrylic rod of 25 mm diameter. It was decided to measure the temperature at depths of 3, 7 and 11 mm from the top surface. To do this, three wells were created in acrylic work piece and thermocouples were placed in these wells. The wells were drilled perpendicular to axis of drill pathway. Total of six samples were made, three for performing the drilling using conventional drill guide and three for performing the drilling using newly designed drill guide.

Two hours prior to starting the experiments, all the instruments including work piece and saline (used as irrigant) were kept in an air conditioned room at 27°C and the testing was performed at the same temperature. The prepared acrylic samples were mounted on a fixture of drilling unit (made to perform the drilling operation) and thermocouples were positioned in the wells filled with thermal paste.

The setup for external irrigation with conventional guide versus external irrigation with newly designed guide is shown in Fig. 4. Each set of experimentation was repeated three times. Irrigant was supplied at constant flow rate with the help of physiodispenser pump and the depth of the drilling was 13 mm. The implant cavity was prepared with contra angled hand piece at a (rotational speed 1200 rpm, contact pressure 1.7 kg and torque 20 Nm).

To simulate clinical operating situation, incremental drilling was carried out in the same cavity. During the drilling process, breaks were taken to change the drill bits and the site was continuously irrigated in that duration. The time taken to change the drill is cool-down time and it’s a standard practice. Data regarding the changes in temperature was logged in a PC using NI data acquisition system and Lab View software.
3. Results and Discussions

The comparison of guides in terms of temperature for newly developed dental drill guide (having better circulation of irrigant at the drilling site) and conventional drill guide is given in Table 1.

Table 1. Comparison of conventional and modified drill guides

| Depth | Conventional drill guide | Modified drill guide |
|-------|---------------------------|----------------------|
|       | Average temperature [°C] | Maximum temperature [°C] | Average temperature [°C] | Maximum temperature [°C] |
| 3 mm  | 32.91                     | 34.35                | 28.29                  | 29.26                  |
| 7 mm  | 38.27                     | 40.64                | 31.06                  | 33.94                  |
| 11 mm | 40.01                     | 43.11                | 36.26                  | 39.54                  |

In the previous studies, many of the researchers had considered dental drill guide culpable for rise in bone temperature during dental implant surgery and explored many options to control it. Misir et al. [9] conducted an in vitro study to determine the influence of surgical drill guide and drilling system on bone temperature and realized that implant site preparation using surgical guides results in added heat generation as compared to classical site preparation no matter which type of irrigation was used. Researchers had tried to control the bone temperature by many means like changing the drill type, drill design, using different irrigation techniques (external / internal), using both the irrigation techniques simultaneously, using low temperature irrigant, changing the drilling parameters (speed, feed, drilling pressure etc) but no one has explored the idea of making changes in the drill guide itself. Gehrke et al. [10] studied the effects of various irrigation methods (external, internal and double irrigation) on bone temperature but did not find considerable advantages of using internal irrigation over the classic external irrigation. However, it was found that double irrigation approach delivers marginally improved outcomes.

Experimental comparison of drill guides shows encouraging results. Average temperature difference of 4.62 °C, 7.21 °C and 3.75 °C at the depth of 3, 7 and 11 mm were found. From the results, it is evident that the new drill guide is capable of achieving the set target. Temperature was reduced at all the locations, which means that flow of irrigant had increased at the surface as well as inside the cavity.

4. Conclusion

In the improved drill guide, irrigation channels provided in the bush / sleeve have resulted in efficient irrigant delivery. The small clearance between internal diameter of bush and drill no longer acts as a barrier for the supply of irrigant and thus improves fluid flow and its contact with drill and bone. The required amount of irrigant can now reach the drilling site without hampering its primary purpose i.e. placement accuracy. The dental drill guide with onsite irrigation delivery system helps in controlling
the bone temperature during osteotomy site preparation because of the presence of local cooling system in the bush. This new drill guide with robust irrigation delivery system is expected to cost about 10% more than the product available in the market.

5. References
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