Bioengineering for Customized Orthodontic Applications- Implant, Bracket & Dental Vibrator

Rajashekar Patil, S. Mohan Kumar, and Shreya Ajmera

***Abstract*—**To understand complex living system an effort has made by mechanical engineers and dentists to deliver prompt products and services to patients concerned about their aesthetic look. Since two decades various bracket systems have designed involving techniques like milling, injection molding which are technically not flexible for the customized dental product development. The aim of this paper to design, develop a customized system which is economical and mainly emphasizes the expertise design and integration of engineering and dental fields. A custom made self-adjustable lingual bracket and customized implants are designed and developed using computer aided design (CAD) and rapid prototyping technology (RPT) to improve the smiles and to overcome the difficulties associated with conventional ones. Lengthy orthodontic treatment usually not accepted by the patients because the patient compliance is lost. Patient's compliance can be improved by facilitating faster tooth movements by designing a localized dental vibrator using advanced engineering principles.

***Keywords*—**Orthodontics, Prosthodontics, Lingual bracket, Implants, Dental vibrator, Computer aided design, Rapid prototyping technology.

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I. Introduction

ARISTOTLE said "Beauty is a greater recommendation than any letter of introduction", this statement is true, nowadays attractive people has a much better chance of being successful in their respective field. Dentists and orthodontists can greatly contribute to enhancing patient's smile, appearance, and subsequently improve their self-confidence. For decades one of the major objections patients had to orthodontic treatment was aesthetics. Patient's interest in more esthetic approaches to malocclusion correction was expressed in the mid-1980s in an increased demand for lingual appliances. Developments in lingual orthodontics at different levels, such as laboratory-based bracket positioning, archwire fabrication, and indirect bonding, have led to a rise in the number of lingually treated patients in Europe and Asia. Yet, when measured the potential of lingual technique, it is still not clearly representing the quality treatment compared with labial or conventional appliances. Usually the orthodontists give various treatment options for malocclusion. The main reasons why they fail to offer their patients a lingual appliance are as follows:

- The bond failure rate is substantially higher than in labial cases.
- The indirect bonding technique is complex and imprecise
- The rotation correction and the finishing process is time consuming
- The patients often have difficulty adapting to the appliance, especially when undergoing lingual treatment in both arches.
- Expensive.

There are number of lingual brackets available in market like conceal, fujita lingual brackets, Forestadent, STB, Kurz lingual bracket etc [1] and each bracket has overcome one or the other reasons mentioned above.

But in contrast to services provided by general dentists, orthodontic therapy often extends over a long period, so not only is the outcome of esthetic significance to the patient, but also the course taken to achieve that outcome. Static mechanical forces in orthodontic treatments move teeth within the jaw bone and rely on force- induced remodeling to elicit tooth movement. Elastics, headgears, expansion devices and other ancillary devices are used to increase the tooth movement. Studies have shown that vibrations to tooth from brushing or ultrasonic scaling have helped in increasing the tooth movement. Hence a cyclical force generating device was designed to determine its impact on rate of orthodontic tooth movement.

Department of prosthodontics deals with treatment modalities like removable and fixed dental as well as maxillofacial prostheses, mainly believes in replacement of missing teeth or maxillofacial structures. Implants are one of the very upcoming treatment modality which gives permanent solution to the missing tooth but at the same time is associated with increased failure rates. The main reasons for their failure are as follows:

- Using the wrong type, size quantity, position or length of the implant thereby causing overloading, may result in implant failure.
- Osteointegration can also fail due to premature loading of the implant restoration.
- Optimal integration of the implant device into the jawbone requires an acceptable level of healthy bone (porosity values, matching of implant size to location

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in jaw, proper site preparation and suitable bone augmentation (bone grafts) if necessary.

Hence the third objective of this article was to manufacture customized implants using rapid prototyping technology according to individual bone height, width and thickness.

The goal of rapid prototyping (RP) technique is to quickly and automatically fabricate 3D objects directly from their CAD models irrespective of their shape complexity without the use of any hardware tools, dies, molds or fixtures specific to the geometry of the object being produced. Current RP systems are based upon a layered manufacturing paradigm. Todd Grim best defined rapid prototyping as "a collection of technologies that are driven by CAD data to produce physical models and parts through an additive process."[2] These technological advances, a new course can now be taken in manufacturing of a customized bracket and implant system, replacing mass-produced prefabricated appliances. In this paper an attempt is made to develop and production of an innovative fully customized lingual bracket, implant and a dental vibrator to give rapid quality and decreased treatment time duration for patients.

II. Methodology

Bracket, implant and dental vibrator are manufactured using forward and reverse engineering. Bracket is manufactured using forward engineering initially 2D drawings are made, converted into 3D drawings, then to stereo lithography (.STL) files and finally .STL file is used to build the part/assembly in RPT. Implant is manufactured using reverse engineering, initially a computed tomography (CT) scan is obtained of patients missing tooth, DICOM files are obtained, imported to MIMICs software to obtain 3D model, the missing area is calculated and implant 3D model is generated and fit to the gap, the desired custom implant is designed and converted to .STL file. Finally .STL file is used to build the part/assembly in RPT.

A. Bracket

The bracket system and associated self-adjusting mechanism is defined, there are other parameters to be satisfied for its successful operations. Some of the major requirements of design and development include:

- Precise slot dimensions (0.457 mm x 0.634 mm) to avoid play at bracket archwire interface
- Smooth finish of the slot to reduce the friction
- Ability to withstand 60-150 gm of force
- Bracket should adjust to lingual anatomy specially on lower anterior teeth because of the smaller size
- Bracket should have multiple surface finish on its different faces
- Reduced man hour in construction and assembly of bracket onto the tooth

As a case study, design and development of a custom-made self-adjustable lingual bracket is explained in the subsequent sections.

The problems traditionally associated with lingual orthodontics cannot be solved with conventional manufacturing process; instead complete individualization of all appliance components is needed. In the approach presented here individualization of the bracket base and recommended torque values for each tooth, are made with state of the art computer aided design/ computer aided manufacturing (CAD/CAM) software coupled with high-end rapid prototyping techniques.

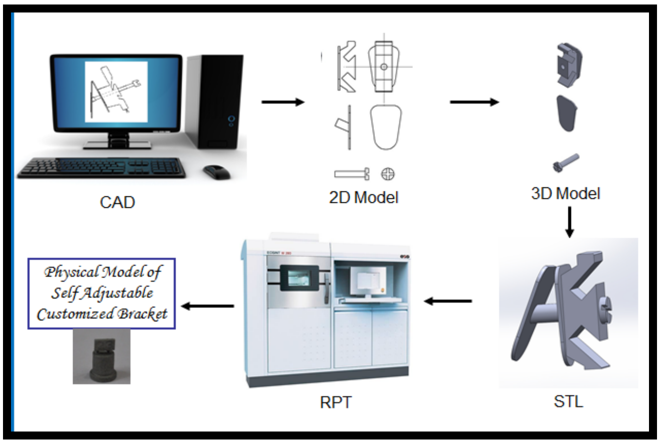

Fig. 1 Schematic representation of bracket manufacturing process

The first step in the manufacturing process is to make a 3D scan of the patient with an extreme accuracy with a resolution of at least 0.02mm, this helps in accounting for minute details present on the lingual surface of a tooth. The CAD files of the bracket already made in the software are altered according to the torque values prescribed by an orthodontists and the base attaching to the tooth modified according to the lingual topography of an individual tooth.

Because of completely adapted base, brackets can be directly bonded by an orthodontist. The vertical height, angulation and torque are thus preset only first order adaptation is performed using the screws which can be adjusted manually. This 3D model is converted into and .STL model and sent to the rapid prototyping machine for processing.

The material used to fabricate the brackets is stainless steel 17-4 according to United States classification and its properties are described in Table I. It has high corrosion resistance, high toughness, ductility and biocompatibility. Its basic composition of Cr, Ni, Cu, Mn, Mo, Nb and C (0.07 wt %).

As metal has been used to manufacture these brackets, the manufacturing process used is laser sintering. Every layer of the powder is melted using lasers itself imparting a very good strength and less prone to deformation.

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TABLE I
PROPERTIES OF STAINLESS STEEL

Properties	Stainless-steel
Ultimate tensile strength	1200 MPa
Yield strength	540±50 MPa
Youngs Modulus	170±20 GPa
Coef. of thermal expansion	14 x 10-6m/m °C
Thermal conductivity (at 100°C)	14W/m°C
Hardness (ground & polished)	Approx. 250 -400 HV1
Operating temperature	550°C
Density	7.8g/cm3
Typical achievable part accuracy	±20-50µm

B. Dental Vibrator

The essence of orthodontic treatment is the movement of teeth through alveolar bone and is the classic paradigm for mechanical stresses causing clinical changes. When force is applied to tooth it tends to move. But how far it moves and how fast it moves all depends upon the reaction of the environment tissue to that force. Thus orthodontic treatment is inescapably mechanical; it is subject to physical laws governing force mechanisms and biologic principles controlling tissue reactions to force stimuli. Yasuda in 1953 demonstrated that a mechanically stressed bone exhibited electrical potentials [3]. Low level electrical currents and potentials have been found to have the capability of bringing about major biologic effects of a very basic nature [4]. Many methods from conventional ultrasonic scaling (vibrations) to nanorobots are available to increase the tooth movement. In this paper a localized dental vibrator has been designed to enhance the rate of orthodontic tooth movement using external application of cyclic vibration. This device applies cyclic forces to move teeth in bone faster through accelerated bone remodeling. The device is a removable orthodontic device, similar to an orthodontic attachment that delivers vibratory forces to the dentition. The device is fully compact with a motor, battery and circuit board in a box of 10 mm3 of a ABS material manufactured using rapid manufacturing technique. The total length of appliance is around 15 mm. The output of motor is connected to vibrator providing cyclic motion on a tooth as shown in Fig. 2. This device is placed near to the tooth which has to be moved and motor is on manually for duration of 20 minutes and put off by manually by the patient. This results in localized accelerated bone remodeling aiding in faster tooth movement.

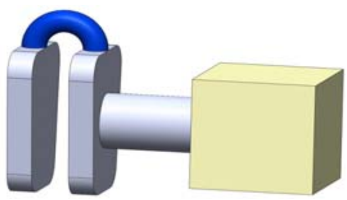

Fig. 2 Representation of customized dental vibrator

C. Implants

Dental implants are routinely utilized to replace missing teeth and have excellent success rates and have several advantages over removable prostheses.

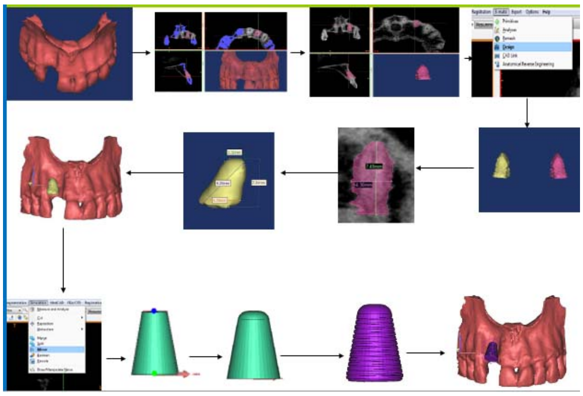

Fig. 3 Schematic representation of customized implant design

To overcome all the difficulties associated with conventionally available implants a further step to provide a customized system of implants was taken based on the height, width and thickness of the bone. The first step in the manufacturing process is to make a 3D scan (DICOM format) of the patient with an extreme accuracy with a resolution of at least 0.02mm, this helps in accounting for minute details of the bony structure. The procedure can be very well explained with an illustration of a missing tooth (right lateral incisor). From second step, is as shown in Fig. 2, the Dicom image is imported in proprietary software (MIMICS 14.01) and thresholded for bone density (1300 to 3000) in hounsfield unit is set to see the bony and teeth structure. The thirst step is to determine the dimension of the implant root. The dimension of the missing tooth is obtained by mirroring the same tooth root on the opposite side; it is edited and designed to the shape of implant as per the bone availability. Finally with appropriate threads on the implant is obtained with suitable abutment.

The designed implant is place in the position of missing tooth and checked for validity in all the three dimensions for its perfect fit virtually as shown in Fig. 3. Implant looks like a tent peg which provides support to the prostheses placed above.

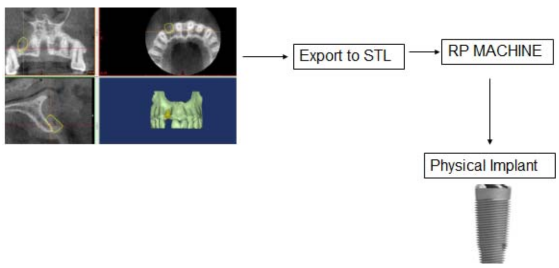

Fig. 4 Schematic representation of implant manufacturing process

This implant now is saved in an .STL format and is assigned for metal properties of titanium. This .STL file is sent

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for processing and manufacturing using selective laser sintering technique of rapid prototyping machine.

III. Discussion

Dentofacial deformity refers to deviations from the normal facial proportions and dental relationships that are severe enough to be handicapping. The affected individuals are handicapped in two ways first jaw function is compromised and second dental and facial appearance often leads to discrimination in social interaction. Dentofacial patients almost have severe malocclusions; these malocclusions are classified as shown in Fig. 2.

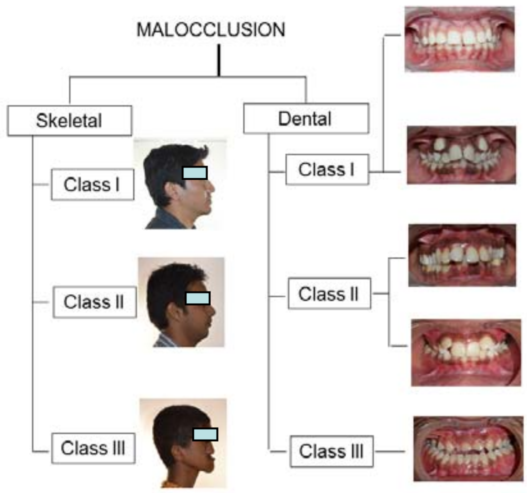

Fig. 5 Classification of skeletal and dental malocclusion

The treatment plan was arrived through the concept of “retro engineering” planning the face first, designing dental movements to facilitate the desired facial outcome using brackets. Brackets on its ground have its own history from its placement on labial or lingual side, on the basis of material used (stainless steel, ceramic, titanium, gold alloy, polycarbonate), on the basis of ligating system etc. In 1980s Dr. Kurz developed the first Lingual appliance system for his patient who was an actress and didn’t want her braces to be seen. Since then Kurz gave seven generation of his bracket system. After reviewing the history custom made self-adjustable lingual bracket has been designed which, would overcome the disadvantages associated with the conventional ones.

This customized system addresses problems traditionally associated with lingual brackets: the brackets are more difficult to bond and tend to debond more often, finishing procedure, laborious and time consuming lab procedures. This custom made self-adjustable lingual bracket has base and main bracket.

Base is customized to the lingual topography making it adapt to the lingual surface resulting in greater bond strength. If the whole bracket (system) does need to be rebonded, the form-fit properties between the bracket base and the tooth provide a positive lock that makes incorrect positioning unlikely.

The main bracket attached to this base using a screw which can be adjusted at distances of 2mm, 2.5mm, 3mm, 3.5mm, 4mm, 4.5mm, 5mm and can be locked at the same position. This helped in eliminating the varied composite thickness between the tooth surface and the bracket base. These two components (base and main bracket) can be angled at any degree according to the patient requirement for torqueing the incisors. The adhesive thickness led to lot of plaque accumulation causing gingival irritation and difficulty for the patient to maintain oral hygiene. This can overall be reduced using a base and the main bracket system.

Most of the lingual bracket system has a single slot for engaging the wire except forestadent, which gives a vertical slot for uprighting spring, Fugita’s lingual bracket having three slots for anterior teeth and five slots for posterior teeth. The present bracket system provides two main slot one is lingual slot 0.022 x 0.028 inches for the main arch wire and the other is occlusal slot 0.018 x 0.025 inches mainly for rotation correction. The mesiodistal correction of the tooth can be easily achieved by the tip value incorporated during the manufacturing process or repositioning of the bracket. In particular, incorrect torque can impact the second order in clinical terms. Stamm et al, for instance, reported that a 10° inaccuracy in torque results in an average vertical deviation of 1.2 mm [5]. This discrepancy occurs when the wire fitting into the slot or the slot size for the wire becomes inaccurate. This has been overcome by the precise manufacturing process of rapid prototyping providing with exact slot size dimensions.

Dental vibrator in theory provides a cyclical force in addition to the standard static force provided by the standard orthodontic treatment. The application of these cyclical forces induces accelerated remodeling of alveolar bone thereby enabling accelerated tooth movement. Mao demonstrated that cyclical forces applied at 2N and with frequencies of 0.2 and 1 Hz for 20 minutes daily provided in conjunction with typical static orthodontic forces provided 24 hours per day induced increased cranial growth, sutural separation and proliferation of osteoblast like cells [6,7]. Thus the hypothetical basis for using this device is to decrease overall orthodontic treatment time. The localized dental vibrator helps in moving tooth faster compared to teeth, according to the requirement of clinician accelerating remodeling of bone in localized area. This unique application of localized dental vibrator makes it different from conventional available ones used for complete dentition.

The electric circuit with an input of a battery of 9V, 2.0A, D.C power supply is used. The battery power is fed to a direct current motor which has a voltage rating of 9V and current rating of 1.5Ampere to drive the motor. The motor used has a speed of 500 rpm and a torque of 0.5Kg for an output of rotational motion of the motor with the off weight is converted to vibratory motion. The electric circuit is shown in Fig. 5.

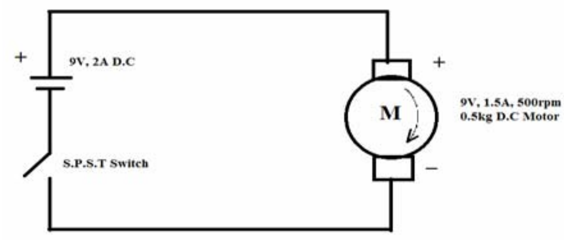

Fig. 6 Circuit diagram of a dental vibrator

A dental implant is a "root" device, usually made of titanium, used in dentistry to support restorations that resemble a tooth or group of teeth to replace missing teeth. Virtually all dental implants placed today are root-form endosseous implants, i.e., they appear similar to an actual tooth root (and thus possess a "root-form") and are placed within the bone.

Dental implant success is related to operator skill, quality and quantity of the bone available at the site, and the patient's oral hygiene [8]. As described in the method recommended height, width and thickness can be achieved using software which reduces the fracture tendency. Failure of a dental implant is often related to the failure of the implant to osseointegrate correctly with the bone, or vice-versa. A typical implant consists of a titanium screw (resembling a tooth root) with a roughened or smooth surface. The bone of the jaw accepts and osseointegrates with the titanium post. Osseointegration refers to the fusion of the implant surface with the surrounding bone. The finish obtained by the process helps enhancing the osseointegrating property of implants which is one of the drawbacks with the conventionally available implants. Other contributing factors to the success of dental implant are placement, as with most surgical procedures. As it is designed for the specific site placing the implant becomes easier as it reduces the chances of being exposed or fenestrated.

Prospectively designed studies evaluating both subjective and objective perceptions are aimed at shedding further light on this matter.

IV. Conclusion

The application of mechanical engineering in dentistry having bioengineering aspects dealing with high quality treatment and patient satisfaction has become an order of the day because of innovation of computer aided design; computer aided engineering and rapid prototyping technologies. The two fields of interest viz., mechanical engineering and dentistry have joined hands together to impart quality treatment by design and development of customized new devices/appliances. The production method presented here for brackets and implants permits any clinical shortcomings to be rectified immediately for the benefit of patients. In addition to the customization of brackets to the existing malocclusion it has helped in eliminating extensive, laborious, time consuming laboratory procedures. Similarly, for customized implants helped in eliminating trial and error method using x-ray, completely by determining dimensions virtually matching according to the available bone type and to the preference of prosthodontist. Bioengineered dental vibrator supports the premise that the rate of orthodontic tooth movement can be enhanced using noninvasive cyclical vibrations for the benefit of the patients.

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