ORIGINAL ARTICLE

A vibratory device to accelerate orthodontic tooth movement

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ABSTRACT
Background and aim: Several approaches have been proposed to accelerate orthodontic tooth movements. One of these technologies is vibrating devices, including the Acceledent device. In this research project, a device similar to the Acceledent device has been designed and fabricated. The therapeutic goal of this device is to promote of orthodontic tooth movement by produce determined vibrations.
Methods: This device consists of the following components: 1- electronic circuit board 2- the body 3- the oral piece 4- the engine and crank wheel 5- rechargeable battery 6- PID control algorithm (proportional-integral-derivative) which calculates the error rate by controlling the output and input values of the process, and corrects the motion and vibration values of the system by sending a signal.
Results: In this device, there is a mechanical vibrations with a frequency of 30 Hz and a force of 0.25 N which the patient will use it for 20 minutes daily. These mechanical vibrations are transmitted to the patient through an oral piece. Garter spring as the interface between the oral piece and the body of the device is responsible for transmitting the vibration from the body to the oral piece. The crankshaft attaching to the electromotor produces the vibration by centrifugal rotation. The PTC Creo 6.0 software was used to designing the body, and 3D printing technology to fabricating the body.
Conclusion: Th whole process of design and prototype production of the Acceledent device were performed during two years. Laboratory evaluations indicated a frequency and a force of the device equal to 30 Hz and 0.25 N, respectively.
Keywords: Vibrator, Orthodontic tooth movement, 3D printing

INTRODUCTION
One of the problems of comprehensive orthodontic treatment for patients and orthodontists is the long treatment time. It usually takes between 2 and 3 years for an orthodontic treatment case to be completed properly, which depends on a variety of factors including the individual's biological response, orthodontic forces, case complexity, skeletal inconsistency, degree of dental camouflage in skeletal problems, treatment mechanics and patient cooperation (1). The first principle for minimizing orthodontic treatment time is proper diagnosis and unique treatment plan for each person. The second principle is in proper biomechanics of orthodontics. In addition to these two principles, several therapeutic methods have been proposed to accelerate orthodontic dental movements (1). These include self-ligating brackets (2), preform coils given by robots (3), low power laser treatment (4), electric current stimulation (5), pulsed electromagnetic fields (6), injection of pharmacological agents such as prostaglandins and relaxin (7) and techniques related to osteogenesis distraction (8), corticosteroids (9), osteoporphosis (10), and low-intensity vibration (11). However, there is limited clinical and scientific evidence for the effectiveness of these techniques (1). The average course of treatment depends on a number of factors, including the specialist's clinical skills, the patient's cooperation with the specialist, and the treatment protocol for whether or not the extraction teeth of patient (12). Increasing the duration of orthodontic treatment will cause several side effects, including increase the risk of decalcification and root resorption (13). The rate of root apical resorption is highly correlated with the overall treatment time (14).

Patient's desire to reduce the duration of treatment, on the other hand, has opened the field for research to accelerate orthodontic tooth movement. Currently available interventions to accelerate alveolar bone regeneration are divided into two groups: surgical interventions and non-surgical interventions (15). Non-surgical approaches include low-power laser radiation (16), magnetic fields (17), mechanical vibrations, and pharmacological approaches such as prostaglandin E2 injection (7). Studies have shown that low-intensity oscillating mechanical stimuli (vibration) can increase the rate of regeneration in force-bearing bones (18), which nowadays it is used to prevent osteoporosis in postmenopausal women due to its promotion of bone metabolism and reduction of bone loss (19). Nowadays, vibrations with a certain frequency have been proposed as a non-pharmacological and non-invasive method to accelerate tooth movement. Animal studies have shown that intensifying vibrations increase the rate of alveolar bone regeneration (20). So far in the United States, the Acceledent device (Orthoaccel, USA) has been introduced to the market, which is also licensed by the FDA. In this study, a device similar to the Acceledent device was designed and built using the above mechanisms, in order to accelerate of orthodontic movement of teeth by creating specific vibrations.

METHODS
Acceledent device consists of the following components, which are: 1- electronic circuit board 2- the body 3- the oral piece 4- the engine and crank wheel 5- rechargeable battery 6- PID control algorithm (proportional-integral-derivative).

Controller design: The controller in this device is PID (Richard L, 1996, Power From the Wind, Cambridge University Press). In fact, PID calculates the error rate by controlling the output and input values of the process and tries to correct the system values by sending a signal. The control mechanism is such that the controller receives the status of the system using a sensor. It then subtracts the measured value from the desired reference value to generate an error signal. The error signal generated by the controller then enters the three blocks of proportionality, integral and derivative.

Body and part design: The design of the body and parts of the device was done by PTC Creo 6.0 software. The internal space was designed to fit the electronic board, motor and crank wheel, battery as well as the connection of the oral piece so that the final size of the device was easy and desirable for patient use. Also, the body material should be light and impact, heat and water resistant.

Engine and crank wheel design: To create vibrations with the desired amplitude and force, it is necessary to use a crankshaft mounted on the shaft of a DC motor. The optimal weight and size of the crankshaft determines the amount of force applied to the device. Also, the crankshaft was placed off-center to produce the desired frequency.

Oral piece: The oral piece meets two prerequisites: First, it can transmit the mechanical forces from the device. Second, its surface is such that it minimizes the accumulation of contamination due to intraoral use. The oral piece consists of three parts, which are 1- a hard core made of polycarbonate, 2- a soft and transparent silicone shell, and 3- the connector part of the oral piece. The construction of the piece is in two steps. In this way, first the piece was molded by plastic injection method and then it was placed inside the second mold by fixtures and clear silicone compatible with the human body was injected and attracted inside the mold. In this way, the vibrations were well transmitted to different parts of the teeth and jaw bones, and the patient could use it more easily.

Frequency determination: The set frequency for the device is 30 Hz, which is controlled by the following way: first, the desired frequency during rotation was determined by mathematical calculations and determining the amount of eccentricity of the crank on the shaft. Then, using an infrared transmitter installed on the board, the information from the encoder rotation will be given to the microcontroller installed on the electronic board, and the microcontroller based on the information given to it can control the engine speed. This method of control is very precise.

RESULTS

Amount of device vibrations: In this device, mechanical vibrations with a frequency of 30 Hz and a force of 0.25 N transmitted to the patient through an oral piece (Figure 1). It is necessary to generate a feedback pulse from the movement of the motor to detect the speed of rotation of the motor. For this purpose, an impeller attached to the shaft was used, which rotates with the crank wheel.

The body of the device: Figure 2 shows a 3D design view of the main body of the device. Section 1 forms the lower half of the garter spring, which is responsible for attaching the oral piece to the main body, and withstands forces. The upper half of the garter is located on the top door of the device. Section 2 shows the stand off bases of the body to the doors, with the help of which the upper and rear doors are installed on the body. Section 3 shows the location of the vibrating motor, which, as can be seen, uses a large number of lateral bases to increase the connection strength of the motor. Section 4 shows the mounting brackets of the printed circuit board, in the middle of which are holes for closing the PCB (electronic circuit board) with an automatic screw. The location of these bases is in accordance with the PCB holes. The body of the device is made of ABS (Acrylonitrile butadiene styrene) polymer. The advantages of ABS polymer include its low cost as well as its structural strength and rigidity. Figure 3 shows the rear view of the main body of the device. The upper wall of the engine mount (No. 1) and the side retaining walls of the body (No. 3) with the PCB mounts (No. 2) are all at the same height, so that the printed circuit board through proper connection to the body can withstand the force of the user due to the pressure of the on and off microswitch of the device. Figure 4 shows the side view of the main body part, which is No. 1 where the mouthpiece is installed, 2 upper doors, 3 back doors and 4 micro USB socket slots to charge the battery and connect the device to the computer.

Figure 5 shows the location of the main components of the printed circuit board. The holes on the board (No. 4) are designed to be exactly on the bases of the main body (No. 2 in Figure 2). The IR transmitter and receiver unit is mounted on the top of the board and behind the board to be located exactly in front of the pulse generator (encoder) impeller installed on the motor. The number 2 in Figure 5 indicates the location of the microcontroller and the flash memory. The on / off switch of the device (No. 3) is installed exactly in the place where, after installing the board on the device, it is located exactly in front of the back door hole. The micro USB socket (No. 5) is installed in the lowest part and on the upper surface of the board, and by installing the board on the main body, it is placed exactly next to the lower wall of the body, thus through the gap on the body it is possible to connect the board to the computer and also to charge the device battery from this port. In order to assemble the device, first, according to Figure 6, the motor (No. 3) enters the motor housing from above and fixed in place by the force coming from the walls. The encoder (2) and the crankshaft (1) are mounted on the motor shaft. The device battery, which can be Li-Ion or Ni-MH, is installed at the bottom of the engine and below the PCB (section 4). After installing the PCB and making the motor connections, the doors of the device are closed and fastened with ABS glue on the body. After that and to use the device, the oral piece is closed on the body and the device is ready to use.

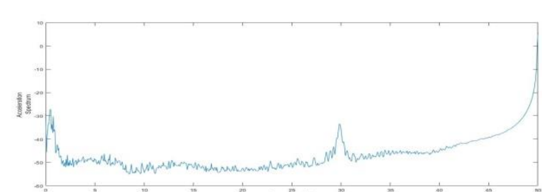

Figure 1- Measured diagram of the vibration frequency of the device (a vibration peak at a frequency of 30 Hz)

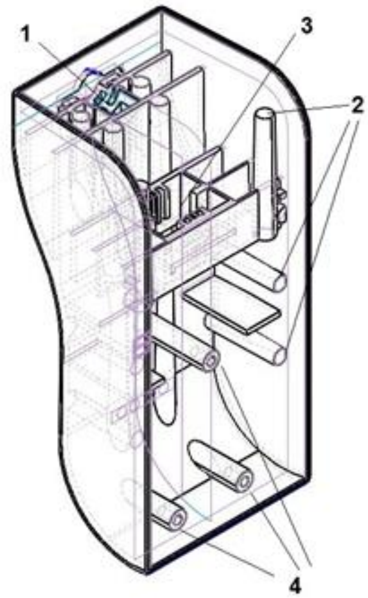

Figure 2 - 3D design view of the main body

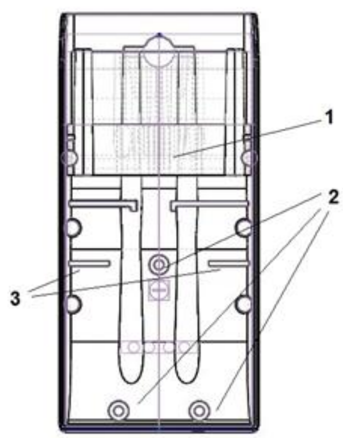

Figure 3- Back view of the main body of the device

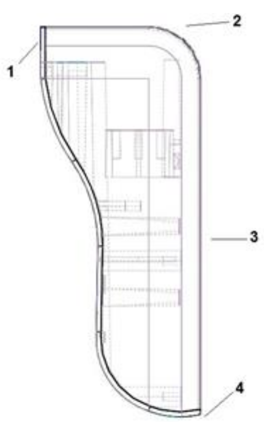

Figure 4- Side view of the main body part

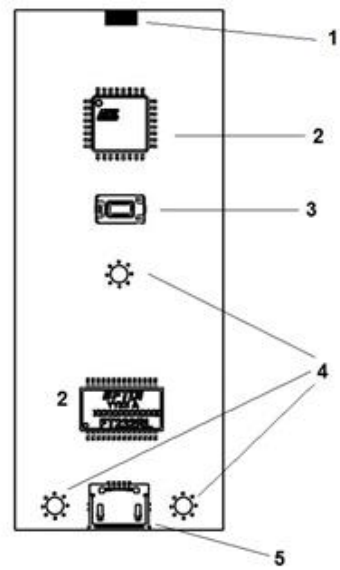

Figure 5 - The main components of the printed circuit board

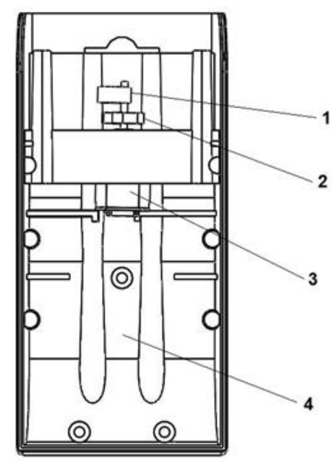

Figure 6- Method of assembling the device

DISCUSSION

The most important view of reducing orthodontic treatment time is that a high percentage of patients undergoing treatment suffer from complications of dental caries. Financial costs, and time spent are other costs that are imperceptibly imposed on the patient and specialist. Also, with the prolongation of the treatment period, the patient's cooperation in various fields will be reduced and therefore the effectiveness of the treatment will be less. The construction of the present device is also an effort in line with this important issue, which is to reduce the treatment time. Numerous evidences from orthopedic research show that mechanical vibration oscillating signals have a positive effect on bone metabolism and increase the rate of renewal in long bones while adapting to mechanical loads (18). This type of mechanical stimulation is currently used as a non-pharmacological intervention to prevent osteoporosis (21). Animal studies have provided evidence from the Schur cranial model (22) and the long bone periosteum (23), suggesting that dynamic loading can significantly improve bone formation. The initial idea of accelerate tooth movement was introduced in a 2008 study by Nishimura et al. (20). They stated that other ways to accelerate tooth movement, such as prostaglandin injections or microosteoporphosis, are associated with side effects such as pain (24) and root resorption (25), which are not pleasant for patients during orthodontics. Therefore, researchers are looking for other ways to accelerate tooth movement in orthodontics. The aim of this study was to prepare a device to accelerate orthodontic tooth movement that can be used in orthodontic patients with minimal problems by using a vibration mechanism with specific force and frequency. Therefore, it was necessary to consider all aspects and malocclusions in the design of the body, especially the oral part, because the goal is to transfer the maximum amount of vibration to the dental system, followed by the alveolar bone, and therefore the thickness of the oral piece in the deep bite's occlusion should be thinner than the open bite.

The results of this study can be summarized in the design of different parts of the vibrator. In the designed device, with the USB connector on the board, it will be possible to charge the device battery through conventional home chargers. In the overall design of the device, the weight of the device was designed to be as small as possible. It is important to control the weight of the device because it reduces the amount of fatigue of the patient's muscles while using the device. Therefore, ABS plastic was used to make the body, which has both strength and light properties. The battery of the device is rechargeable type of 100 mAh. The motor of the device is a series of DC motors with a shelf life of about 500 hours. The silicone surface of the oral piece prevents the growth of bacteria due to its impermeability and lack of surface pores. The initial models of the device were made by 3D printers, and the final device was prepared and made after fixing the defects of the prototype. Based on increasing evidence, low-power periodic mechanical loading has an anabolic effect on bone metabolism and stimulates regeneration in long bones, vertebrae, and cranial joints. On the other hand, this type of force also stimulates the orthodontic movement of teeth in rodents (1). In a clinical trial (26) in the San Antonio Department of Orthodontics, Texas, the effect of vibration was assessed by an AcceleDent device (OrthoAccel Technologies, Inc., Bellaire, Tx) on dental movement in orthodontic patients. Their aim was to evaluate the effect of mechanical stimulation of the AcceleDent device for 20 minutes per day on the accelerate tooth movement in orthodontic patients. This device generated a vibration force of 25 grams with a frequency of 30 Hz. Preliminary findings showed that the initial sorting speed in the vibration group increased by approximately 51% (26).

AcceleDent is becoming increasingly popular as an adjunct to Invisalign therapy among specialists in the United States and around the world. Studies show that when AcceleDent is used during treatment with Invisalign, treatment time can be reduced by up to 50%. Researchers have shown that when vibratory force is applied, the time to use each liner can be reduced from 2 weeks to 1 week. It is generally accepted that strong contact of the liner with the surface of all teeth allows more efficient transmission of vibration to the root and surrounding bone (1). Different signaling pathways have been shown in response of bone cells to mechanical loading (29). Osteocytes have also been identified as cells that respond to mechanical stimulation (30). Very soon, within 6 hours after the onset of mechanical loading, several messages are generated in the expression of osteocalcin genes and dentin matrix proteins in alveolar osteocytes. These mechanically induced signaling pathways can be triggered by fluid shear stress in the lacunae and osteocyte canaliculus or by the piezoelectric potential induced by bone flexion. In addition, bone microfractures may be an accompanying factor in response to oscillating loading. It has recently been shown that these events of the mechanical response in osteocytes cause increased differentiation of osteocytes (31) and stimulation of bone-specific genes (alkaline phosphatase type 1) (32). On the other hand, animal studies show that alternating cycle vibration forces accelerate the laboratory orthodontic movement of teeth (31). Loading the device with a pulsating force for 1.5 hours per day for 3 weeks almost leads to an accelerate movement of the teeth compared to the static loading, which does not include tooth root resorption (24, 28). The molecular mechanism of vibration transmission with a frequency in the range of 60 Hz on the dental bone increases the expression of RANKL by fibroblasts and osteoclasts in PDL tissue. After the publication of the results of these studies, a opportunity was provided for human studies to conduct clinical trials, and the effect of periodic vibrations on accelerate orthodontic movement of teeth (28-32).

It seems that using AcceleDent for 20 minutes per day is not enough, because in animal studies, researchers got better results by using AcceleDent daily for longer periods of time. Therefore, it is recommended to increase the vibration time to twice the current time. In the case of patient tolerance, vibration can be performed at regular intervals. For example, three times per day, each time for 15 minutes, to reduce patient discomfort. About the current frequency used in our designed device, no study of how to initialize this frequency has been presented yet, however, in another study, 30 and 60 Hz frequencies were tested on mice, the results of which showed that the frequency of 60 Hz has a greater effect on orthodontic movements (31). Therefore, in future studies, these two frequencies can be tested in terms of feasibility and patient comfort, which can be easily done in the current device through a software command.

CONCLUSION

All stages of designing and prototyping the Acceledent device were done during two years. Laboratory evaluations indicated a frequency of 30 Hz and a force of 0.25 N.

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