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치과 핸드피스 드릴의 각도 보정 장치의 개발

Development of angle correction apparatus for dental handpiece drill

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남 윤

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Abstract

The preparation of uniform angle of wall is essential in fixed prosthesis. It has been known that the ideal convergence angle for prosthesis is ranged from 5° to 12°. However the average convergence angle formed in clinical field was ranged from 14° ~ 20°. Increase in convergence angle is the major cause of reduced retention and may lead to the adhesive failure, the second most frequently occurring problem in fixed prosthesis.

In this study, we developed a *de novo* detachable angle-correction apparatus for dental handpiece drill which could help preparation of tooth successfully. We would like to introduce its efficiency on full veneer tooth preparation in single crowns and 3-unit bridges.

To measure the angulation of dental handpiece, we utilized gyro sensor, acceleration sensor, and Kalman filter algorithm. Gyro sensor can measure angular velocities to calculate slope of an object by integrating them. Acceleration sensor can also calculate slope of an object by measuring acceleration relative to gravity. However, accuracy of acceleration sensor is vulnerable to translational movement and shows inconsistent values. In case of gyro sensor zero point shifting occurs as the time goes by. To compensate those problems Kalman filter algorhythm is used in this study. The device developed in this study is directly attached to handpiece body thus a

specific matrix equation is used to convert the angle of handpiece body to handpiece drill. Various handpieces can be used in this system by simply put the cervical angle of them.

Converting the angulation of handpiece body to its drill part could be gained by a specific matrix formulation set on two reference points (2°, 6°). Flexible printed circuit board(FPCB)was used to minimize the size of device, improving clinical usefulness; the maximum diameter of this apparatus is 26 mm.

Zero point error, convergence angle, tooth axis deviation analysis were performed to examine the efficiency of de novo detachable angle correction apparatus. We measured angulation values from various angles (0°, 30°, 60°, 80°, 90°) for x-axis in stationary state to evaluate a zero point error of the device.

Sixteen volunteers were recruited to participate in this study. Fourteen of them were dental students (third and fourth grade, school of dentistry, Seoul National University) and two of them were residents in the department of dental prosthetics. They were divided randomly into two groups(group 1, 2). The only difference between these two groups was the point of time of using the device. For the convergence angle investigation, each practitioner performed tooth preparation on mandibular first molar resin tooth. 1.5 mm punch-out on occlusal plane was used as a reference. For the tooth axis deviation, commercially available ideal abutment model of mandibular first premolar tooth was used as a reference. All abutments were scanned by 3D scanner (D700, 3Shape Co.). The convergence angle and tooth axis deviation were analyzed by CAD program (Solidworks 2013, Dassault systems Co.). Statistical analysis was performed using paired t-test. Statistical significance was defined as $P<0.05$ (SPSS 21.0, IBM Co.).

This device successfully maintained stable zero point (less than 1° deviation) at different angles (0°, 30°, 60°, 80°) for the first 30 minutes. However, after 30 minutes, zero point moved for 1.16° at 90°. In single tooth preparation, without this apparatus, the average bucco-lingual (BL) convergence angle was 20.26° (SD 7.85) and the average mesio-distal (MD) convergence angle was 17.88° (SD 7.64). However, using this apparatus improved the average BL convergence angle to 13.21° (SD 4.77) and the average MD convergence angle to 10.79° (SD 4.48). Furthermore, the angle correction device showed a statistically significant effect on reducing convergence angle of both directions regardless of the order of the direction ($p = 0.005, 0.001$ for bucco-lingual, mesio-distal, respectively).

In addition, in 3-unit bridge tooth axis deviation, without this apparatus, the average BL tooth axis deviation was 3.86° (SD 2.99) and the average MD convergence angle was 2.12° (SD 1.32). However, using this apparatus improved the average BL convergence angle to 2.00° (SD 1.47) and the average MD convergence angle to 1.71° (SD 1.33). The angulation correction device had a statistically

significant effect on reducing BL tooth axis deviation regardless of the order of using the device ($p = 0.039$). Although there was a reduction of tooth axis deviation on MD direction, it was not statistically significant.

The angle correction device developed in this study is capable of guiding practitioner with high accuracy comparable to commercial navigation surgery. However by succinctly minimizing the operative mechanism, volume of the angle correction device is much smaller than any other commercial navigation surgery system.

This device is expected to be widely utilized in the various fields of orofacial surgery. For instance, when a practitioner does abutment preparation, multiple implant placement, or orthodontic bracket attachment the angle correction device will provide accurate guidance to achieve maximal clinical output. In addition, this device can be used to educate and train dental students by helping them to learn the proper sense of angle and position. In the field of OMFS, the angle correction device will help surgeon to maintain a certain degree of precision under the situation having poor visibility or esthetically important surgery.

Keywords ; Angulation correction device, convergence angle, tooth axis deviation, Gyro sensor

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Contents

I. Introduction

Today, the needs for precise dental procedure have been increased. In tooth preparation and implant placement which are the two main axes of modern dental procedures, there is a myriad of developments to meet those needs. Accurate dental procedures not only can improve the quality of it but also can reduce the time required, allowing the minimally invasive technique to reduce postoperative complications.[1] The accuracy of angulation is especially emphasized for tooth preparation of full-crown and placement of implant fixture. While functioning, in order to keep them stable on the tooth, the proper resistance and maintenance of abutment form are necessary. The maintenance of cast prosthesis is determined by convergence angle of abutment, contact area, the inner surface roughness of the structure, and so on.[2,3] Among them, the convergence angle is considered as a primary factor and most of all studies have been focusing on it.[4] The definition of convergence angle is 'the angle between opposing axial walls and has been shown to affect crown retention'. It has been known that the optimal convergence angle is ranged from 5° to 12° .[5,6.]

Also, the accuracy of angulation in dental procedure is important for minimizing the adverse effect, assuring best aesthetic result, and maintaining proper oral health. Ideally, the implant should be placed in parallel with other adjacent implants or remaining tooth. This results in the implant to be applied to the vertical occlusal force. In particular, when more than one dental implant has been placed, the angle between implants affects the maintenance of upper prosthesis. A study on the relationship between retention of the prosthesis and inter–implant angle in 24 overdenture wearing patients reported that as inter implant angle was increased, retention of implant overdenture using locator attachment was significantly decreased.[7] In addition, when using the angled abutment to compensate the angulation error, the stress on implant and surrounding bone has been found to be increased. However, the increased stress did not exceed physiological limit.[8] As such, the correct angulation is important in the dental technique, however, using a dental hand piece, there must be a discrepancy between reality and theory. This discrepancy is well–described in the studies about convergence angle of the abutment for casting crowns. Analysis of the convergence angle of the 478 clinically formed abutments reported that the actual average convergence angle was 21° and there was a great variance among the dentists.[9] Other studies also supported that by reporting the average convergence angle ranging from 14° to 20° and this is considerably deviated from the ideal value.[4,10] An increase of convergence angle results in a reduction of the average retention force regardless of the type of cement used.[11] In fixed prosthesis, the most frequently occurring problem was porcelain fracture (16%) and the second frequently occurring problem was adhesive failure(15.1%) due to insufficient retention. This retention problem can be prevented by maintaining the convergence angle in the certain range mentioned above.[12] Technically this problem occurs because most dental procedures using handpiece solely rely on spatial perception of dentist. In particular, due to physiological limitations of the human being, it is very difficult to achieve an ideal angulation in 3-dimensional space and thus most dentists have difficulty in performing ideal procedures. To compensate human error caused by those limitations and improve quality of dental care, it is necessary to develop a guiding device that can objectively measure the angulation of handpiece drill and indicate the measured value accurately. In particular, Implant placement procedure has already reached a level of computer-guided navigation system that implements the preoperative planning, surgical guiding, and optical tracking device.[2,13] Also, there is a method using electromagnetic tracker and a direct surveying apparatus such as Parallel-A-prep.[14,15] Despite these technical advances, there are many challenges to overcome in order to use computer guided navigation system in clinical field. When a dentist uses surgical guide or optical tracking device, he/she needs to tolerate bulky and expensive hardware with complicated manuals. In addition, errors can occur when applying a surgical guide and optical tracking device. For example, it is practically impossible to guarantee that device can be perfectly suited to all the patients in all surgical situations. According to a previous meta-analysis of 18 studies about accuracy of surgical guide showed that an error at the entry point was 1.07 mm(95% CI : 0.76-1.22 mm) and at the apex 1.63 mm(95% CI : 1.26-2 mm). The mean error in height was 0.43 mm(95% CI : 0.12-0.74 mm) and mean error in angulation was 5.26° (95% CI : 3.94° - 6.58°).[16] Those errors deviated from the ideal value can damage anatomical structures or increase failure rate. According to the authors, there is a large variation of deviation among the studies. Therefore reliability of the computer-guided system is not accurate enough to achieve a 'blind' implantation.[17] In addition, in case of the electromagnetic tracking device, there is a critical limitation; metal prosthesis in oral cavity can cause error. Also, referencing and navigating process itself can be time-consuming.[13] In case of Parallel-A-Prep, mounting procedure is cumbersome and volume of the device is too big. To overcome these limitations and take advantages of computer guided navigation system, it is necessary to develop new device which can reduce interference by minimizing, simplifying the device, is not affected by environmental factors such as a metal prosthesis in oral cavity, can maintain the accuracy of conventional method, is cost-efficient , is intuitive and easy to use, can tolerate high-pressure sterilization process and, is detachable.

In this paper, a *de novo* detachable dental angulation correction device is proposed to overcome the disadvantages of conventional guiding devices and to achieve the requirements listed above. This simple and small device does not have additional compartment such as camera or electromagnetic sensors thus there is no error caused by environmental factors such as metal prosthesis. In addition, because of its small size, it can be attached to the anterior drill-containing part of handpiece, which is rotatable along the axis of the handpiece body. Most importantly, this device does not display angulation of hand piece body but displays angulation of dental drill which is clinically significant. The effectiveness of this device was examined by *in vitro* tooth preparation test using dental phantom® (Nissim type1, Nissan Co.). Full crown preparation is one of the most basic techniques for dentists but level of technique required to achieve the ideal result would be higher than placing implant fixture because it is harder to maintain firm support during the preparation of tooth than implant fixture placement.

II. Materials and Methods

1. Design and Development of the Device

1) Principle of measuring angulation

We used MPU-6050 module (containing gyro sensor and acceleration sensor) commercialized in the field of mobile device and drone for measuring three-dimensional angulation of dental drill. The gyro sensor and acceleration sensor measure angular velocity and relative acceleration of gravity respectively. When integrating the angular velocity measured from the gyro sensor angular deviation can be obtained from the original state. Also, using acceleration sensor, it is possible to measure the extent of the device tilted from the original state by measuring acceleration relative to the gravitational acceleration. Both sensors have complementary pros and cons. Although the stabilized value of the gyro sensor is sensitive to a single rotation, its reliability decreases over time because of the phenomenon called zero point shifting. In the contrary, acceleration sensor shows no zero point drift with the lapse of time but its accuracy is venerable to translational movement. To compensate errors caused by those technical limitations, several algorithms such as the Kalman filter have been applied.[17] For the device developed in this study, gyro sensor and acceleration sensor are simultaneously utilized to calculate angle of the drill with applying Kalman filter algorithm.

2) Computation & display process

The computational process of the device can be divided into three. The first process is to set the reference angulation. This process begins with contacting the tip of drill with tooth surface; at the contact point, practitioner press the pedal with free foot to save the spatial angle of the sensor called reference angulation.

After saving the reference angle, the second process is to translate three axial angles of the handpiece body to those of dental drill. Almost all the commercially available hand pieces have drill-containing head part that is not parallel to hand-holding body part. When the angle between the head and body portion of the hand piece is "θ", the angle between one line that is perpendicular to the sensor and another line that is extended from the axis of drill is also "θ" (Fig 1a).

Therefore, as depicted in figure 1b and 1c, specific formula translates the three axial angles of hand piece body(x', y', z') into those of dental drill(x, y, z). In addition, this process increases clinical efficacy of the device because it is dental drill that grinds the tooth, not the hand piece.

The third process is to track the change in angulation of three axis caused by the rotation of handpiece (from x_1, y_1, z_1 to x_2, y_2, z_2). Since rotation of dental drill along the z-axis does not changes the clinical spatial angle, this device only displays angulation for x− and y− axis. Using this bypass, clinicians can exclude the error caused by simple positional change of hand and body.

In addition, this device uses two reference points. The first reference point is 2 degree which is set by the author. The LED indicators of each axis flash when the dental drill is out of the tolerable angular change (2 degree for each reverse axis). If the handpiece drill is located in the first reference position the LED indicators are automatically switched off.

Therefore, the clinician is able to constantly obtain original angulation when he/she tilt the drill according to the flashing LED indicators. For instance, when the drill is tilted toward +x direction for 3 degree, the LED indicator of −x will blink. If clinician adjusts the angulation by tilting drill toward −x direction, the LED indicator for −x will be turned off. The indicators for x,y aixs of dental drill operate independently. The second reference point is 6 degree which is set by the author. The LED indicator for each axis are going to be turned on constantly when the dental drill moved out of the second reference angle (6 degree) for each reverse axis. For example, when the drill is tilted toward +x direction for 10 degree, the LED indicator of −x will be turned on. If clinician adjusts the angulation the dental drill to the right position, it will be turned off or blinked.

3) Software

Every software for this device use arduino 1.0.1. Source code of the Kalman filter algorithm is described in ardunino forum(http://forum.arduino.cc/)

4) Use of flexible electronic circuit board (fPCB)

This device utilizes flexible PCB and this material helps to dramatically reduce the size and thickness of the device and improve clinical efficacy (Fig 2). To comfortably grab this device within the space between the index finger and thumb, the maximum diameter of the apparatus should be less than 26 mm.

2. The effectiveness and efficacy of device

1) Zero point drift

To evaluate a zero point drift of the device, we measured x angulation values from various angles(0° , 30° , 60° , 80° , 90°) when the device is in the stationary state. Data were collected for 30 minutes. According to *in vitro* studies, the minimum security distance was recommended as 1 mm.[18-20] The '30 minutes' criteria was made to simulate enough time for each daily dental practices. Thus, in this study, we defined the stabilized zero point as 'less than 1 mm deviation for 30 mins.'

2) Reduction of convergence angle during single crown preparation

Sixteen volunteers were recruited to participate in the study. Volunteers were composed of fourteen dental students(third and fourth grade of Seoul National University school of dentistry) and two prosthetics residents. They were divided randomly into 2 groups(1, 2). The only difference between these groups is the timing of using the device. Dental simulator® (Nissim type1, Nissan Co.), Dentiform® (PRO2002-UL-SP-FEM-28, Nissan Co.), #36 tooth model® (A5A-200, Nissan Co.) were used.

When the volunteers used the apparatus, they made 1.5 mm-deep punch out (reference angulation), which was parallel to personally preferred tooth axis at the center of occlusal plane. According to the instruction of apparatus, the volunteers performed tooth preparation within the range of 2 ° ~ 6 ° deviation from the reference angulation. When they did not use the apparatus, they performed usual tooth preparation for full veneer gold crown without marking reference angulation.

All abutments were scanned by 3D scanner® (D700, 3Shape CO.). The convergence angles were analyzed by CAD program® (Solidworks 2013, Dassault systems Co.). The midlines of each axial wall were selected to measure convergence angle. Data were statistically analyzed by paired t-test(α=0.05). SPSS Statistics 21.0® (IBM Co.) was used.

3) Reduction of convergence angle during 3-unit bridge crown preparation

Sixteen volunteers were recruited to participate in the study. Volunteers were composed of fourteen dental students (third and fourth grade of Seoul National University, School of dentistry) and two prosthetics residents. They were randomly divided into 2 groups(First, Later). The only difference between these two groups is the timing of using device. Dental simulator® (Nissim type1, Nissan Co.), Dentiform® (PRO2002-UL-SP-FEM-28, Nissan Co.), #36 tooth model(A5A-200, Nissan Co.), #34 ideal abutment model® (A21A-LL42, Nissan Co.) were used to mimic the real clinical situations.

The axial walls of #34 ideal abutment teeth were used as a reference. When the volunteers used the apparatus, according to instruction of the apparatus, they performed tooth preparation within the range of 6° deviated from the reference angulation. When the volunteers did not use the apparatus, they performed usual tooth preparation for 3-unit bridge prosthesis without setting reference point.

All abutments were scanned by 3D scanner(D700, 3Shape Co.). The convergence angles were analyzed by CAD program(Solidworks 2013, Dassault systems Co.). When observed from fixed point of view, the line between the centers of gravity at the top and bottom surface was defined as tooth axis. By measuring the discrepancy between those points, and height of abutment, we could obtain tooth axis angulation for each directions (Fig 3). To analyze tooth axis deviation, we measured the angle between tooth axes of #34 and #36 abutments. Data were statistically analyzed by paired t-test(α=0.05). SPSS Statistics 21.0®(IBM Co.) was used.

III. Result

1) Device

The maximum diameter is 26 mm. Figure.4 shows appearance and operation of the device (Fig 4). There are two reference points : 2 ° (blink) and 6 ° (constantly turn on). When the angulation of the drill deviate from the reference for 2 ° , the LED indicator of the opposite direction(same axis) blinks. The practitioner should tilt the handpiece drill toward the direction which LED indicator blinks. The LED indicators of different axis operate independently. Since the z−axis is parallel with the drill, one can ignore rotation along it. Therefore, despite of angle adjustment in 3−dimensional space, there are only 2 directions to adjust.

2) Zero point drift

For the first 30 minutes, a *de novo* angle correction device successfully maintained stable zero point (less than 1° deviation) at the four different angles (0° , 30° , 60° , 80°). We measured the angle of 3 axes at every 0.1 second. According to the previous *in vitro* studies, the minimum distance recommended for implant surgical guide to prevent the damage of anatomical structures is 1 mm.[18−20] For wider clinical application, we used the same criterion for our device. Figure 5 showed average zero point movement after 30 minutes. However, after 30 minutes, zero point moved for 1.16° at 90° (SD 0.046). Figure 5 showed average zero point drift after 30 minutes(Table 1).

3) Convergence angle

When not using the apparatus, the average bucco-lingual convergence angle was 20.26° (SD 7.85) and the average mesio-distal convergence angle was 17.88° (SD 7.64). When using the apparatus, the average bucco-lingual convergence angle was 13.21° (SD 4.77) and the average mesio-distal convergence angle was 10.79° (SD 4.48). The angle correction device showed a statistically significant effect on reducing convergence angle for both directions regardless of the order of the direction ($p = 0.005$, 0.001 for bucco-lingual, mesio-distal, respectively)(Fig 6)(Table 2).

4) Tooth axis deviation between 3-unit bridge abutments

When not using the apparatus, the average bucco-lingual tooth axis deviation was 3.86° (SD 2.99) and the average mesio-distal convergence angle was 2.12° (SD 1.32). When using the device, the average bucco-lingual convergence angle was

2.00° (SD 1.47) and the average mesio-distal convergence angle was 1.71° (SD 1.33). The angulation correction device had a statistically significant effect on reducing bucco-lingual tooth axis deviation regardless of the order of using the device ($p = 0.039$). Although there was a reduction of tooth axis deviation on mesio-distal side, it was not statistically significant (Fig.7)(Table 3).

IV. Discussion

In this study, cylinder-shaped hollow detachable angle correction device was developed, and this device was tested on tooth preparation for full veneer and 3 unit-bridge prosthesis. Recently, several attempts of utilizing gyro sensor, acceleration sensor on dental handpiece have been made.[21,22] However, those projects were just conceptual and thus not commercialized because of numerous technical and clinical hurdles. First, the size of devices was not compact enough to use, and secondly, the sensors were only able to detect the angle of handpiece body, not the drill. Another main purpose of this study is to minimize inevitable human errors in various types of tooth preparation with sensor-mounted devices. In this aspect, this study is expected to prospect the field of improving technical accuracy in various types of dental practice.

Convergence angle of abutment largely affects the retention of restorative materials. Convergence angle can be defined as "the angle between opposing axial walls" and has been showned to affect crown retention and it also has been known that the increase of convergence angle reduces retentive force regardless of the types of cement.[5,11] In case of fixed prosthesis, the second most frequently occurring problems is adhesive failure of prosthesis due to insufficient retention, and this problem can be prevented by simply increasing convergence angle. [12]

Using gyro sensor, angular velocity was recorded and this value is integrated to measure rotational angle. In case of conventional devices that have been using this mechanism, accumulated error causes the drift of zero point. In contrast, acceleration sensor detects relative acceleration corresponding with gravitational acceleration and thus the drift of zero point is negligible but has problems with obtaining the slope since its accuracy is venerable to external force and translational movement. To compensate these errors filtering algorithms such as the Kalman filter algorithm and compensatory filter algorithm were developed.[17] In this study zero point shift at various angles (0°, 30°, 60°, 80°, 90°) were observed. To mimic the clinical condition all the data were collected for 30 minutes. Zero point shift less than 1 degree, proved as the minimum error for implant guide surgery in the previous studies, was set as standard.[18-20] The result showed that there was no zero point shift observed except when the device was placed at 90° for 30 minutes. However, this shift is clinically negligible because maintaining handpiece in perpendicular position for 30 min without any movement does not likely occur. The zero point shift measured in this study were time-dependent average values but the raw data showed a outranged value deviated from zero point for an instant moment(0.1s)(Fig 8). However, this outranged value can be considered as spontaneous noise thus it can be said that there was no problem with maintaining zero point value.

The practitioner group using the device developed in this study showed significantly decreased convergence angle (MD p=0.001, BL p = 0.005). For the practitioner group using conventional handpiece, convergence angle values were MD 17.88°, BL 20.26°, close to the value from the previous researches 21°, 14° ~ 20°.[4,10] Another advantage from using this device is improved consistency; distribution of data collected in each trial was decreased from MD 7.64°, BL 7.85° to MD 4.48°, BL 4.77°. For the #36 single crown full veneer preparation there was significant decrease in both average convergence angle and distribution at bucco-lingual and mesio-distal sides. This suggests that the device actually improves not only accuracy but also precision of practitioner's work thus guarantees more credible result.

In case of preparation for 3-unit bridge prosthesis, axis of #34 tooth was set as standard for the preparation of #36 tooth. After that, angle between axis of each abutment was measured. For the bucco-lingual side, the average angle between two axis was decreased from 3.86° (SD 2.99) to 2.12° (SD 1.32) with statistical significance (p=0.039).

In case of the preparation for 3-unit bridge prosthesis, angle between two axes was decreased from 2.00° (SD 1.47) to 1.71° (SD 1.33) at mesio-distal side, but this change was not statistically significant (p = 0.473). Two possible explanations can be discussed here; first, it is easier for practitioner to perform surgical procedures with better accuracy at mesio−distal side than bucco−lingual side. In the previous studies showed the fact that experienced surgeons had significantly less error in bucco−lingual angulation.[23] Based on this result, it is possible to deduce that surgical procedure on mesio−distal side requires less level of technical difficulty than bucco−lingual side and this difference is due to the caused by arrangement of teeth. Therefore, improvement of clinical efficacy by using this device is less dramatic at mesio−distal side. Secondly, since the mesio−distal length of mandibular molar is longer than bucco−lingual length of it, the same 0.5~1 mm preparation of different sides of teeth might have resulted less amount of axial movement at mesio−distal side. Less amount of axial movement caused less difference in angle between the two axes and thus the value became statistically insignificant.

In this study a device that can recognize and save the angle of handpiece drill is developed and the angle data collected from this device can be integrated and displayed to improve practitioner's accuracy in his/her dental procedure. The clinical efficacy of this device was tested in dental simulator considering various clinical aspects. However, the data collected from the test cannot perfectly reflect real clinical situations because patient's head and mandible are not fixed as in the dental simulator. Therefore the next generation of this device should be attachable to relatively fixed anatomical structure of patient. In addition, considering the fact that the angle detection by gyro sensor and acceleration sensor is venerable to external force such as tremor, use of vibration−proof materials on this device for low speed handpeice or implant drill is highly recommended.

V. Conclusion

In this study, We developed a *de novo* detachable angle-correction apparatus for dental handpiece drill which has minimized volume and improved convenience. The device maintained stable zero point at various different angles, except 90°. When the practitioners used the device, there were significant reductions of convergence angle of single crown abutment for both directions. ($p = 0.005, 0.001$ for BL, MD, respectively). When the practitioners used the device, there were significant reductions of tooth axis deviation of 3-unit bridge abutment for BL direction.($p = 0.039$). This device can be utilized at various fields of dentistry such as tooth preparation, implant placement, orthodontics, education for novice dental students. In addition, This device can be utilized in the field of oral and maxillfacial surgery, such as implant placement, blind surgery, esthetic surgery

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Figure legends

Figure 1. (A) Angled configuration of the handpiece. When the angle between the head and body portion of the hand piece is “θ”, the angle between one line that is perpendicular to the sensor and another line that is extended from the axis of drill is also “θ”.
(B, C) Body to head transition matrix formula translates the three axial angles of hand piece body(x’, y’, z’) into those of dental drill(x, y, z). Because of this formula, we don’t have to make different electric circuit board for every different type of handpiece. Since it is dental drill that grinds the tooth, not the hand piece, this process improves clinical efficacy of the device.

Figure 2. At first, an experimental electric circuit was tested on the bread board(A), and then it was printed on normal printed circuit board(PCB)(B). By using bending property of flexible PCB, the device could be rolled around the handpiece. This dramatically reduced the diameter of the device(from 46 mm to 26 mm). According to the spatial coordination of the circuit board, 3D model and prototype were made(C,D).

Figure 3. The Definition of tooth axis (A), tooth height (B), and Tooth axis angulation (C).

(A) When observed from fixed view point, the line between the centers of gravity at the top(red spot) and bottom(y) surface was defined as tooth axis of abutment. When the center of gravity of the top and bottom surface is (x_t, y_t, z_t), and (x_b, y_b, z_b),
then, tooth axis is

$$\overrightarrow{Axis} = (x_t - x_b, y_t - x_b, z_t - z_b)$$

(B) We defined the height of the abutment as the distance from the upper abutment margin to bucco-mesial cusp tip.
(C) Using inverse tangent function, we could obtain tooth axis angulation for each directions.

Figure 4. An angulation correcting device is mounted to the hand piece (top view : A), it is mounted to the hand piece (side view : B), Practitioner could place device attached-hand piece in the cradle (C), the drill' s -X deviation from the reference(D), a regression to the reference, all LED indicators were turned off at reference angle(E), example of actual use (F)

Figure 5. Zero point drift after 30minutes at various angle, showing average zero point drift after 30minutes at different angle of the device. At five different angles (0° , 15° ,30° ,60° , 80°), the zero point drift was less than 1° . The 1° deviation criteria for correcting device is recommended from previous *in vitro* studies.

However, at 90° , the average zero point drift exceeded 1° deviation(1.16°).

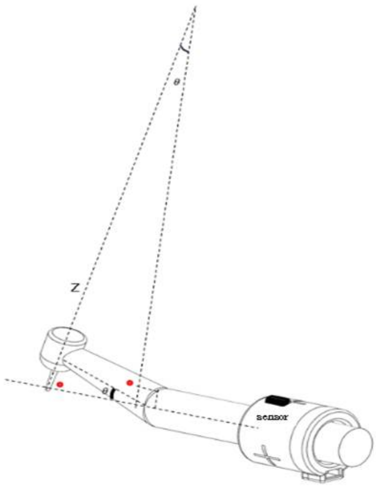
Figure 6. The effect of correcting device on convergence angle for bucco-lingual direction(A) and mesio-distal direction(B).

Figure 7. The effect of correcting device on tooth axis deviation for bucco-lingual direction(A) and mesio-distal direction(B).

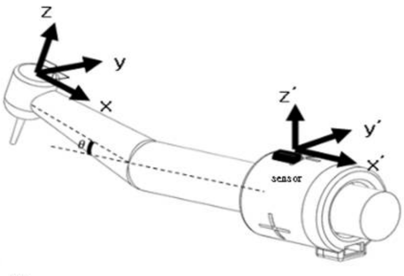
Figure 8. The law data of zero point angle of x-axis at 30° for 10 minutes, showing the drift of zero point during 699 seconds t 30 degree. There are three arrows(full line arrow, dotted line arrow, arrow head) which indicate outranged values. The full line arrow shows 'zero point adjustment process' which is always occurred at the beginning of the device operation. It spends less than 1 second. There were other outranged values for an instant moment(0.1s)(dotted line arrow and arrow head). However, this outranged value was considered as a spontaneous noise because it didn't induce any problem with maintaining zero point value.

Figures

Figure 1.



(A)



(B)

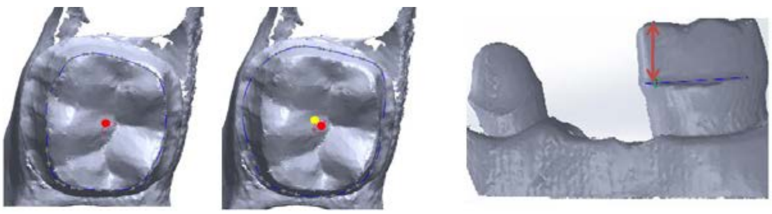
$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

(C)

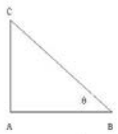
Figure 2.

(A) (B) (C) (D)

Figure 3.



(A) (B)



$$\theta = \tan^{-1}(\frac{\overline{AC}}{\overline{AB}})$$

(C)

Figure 4

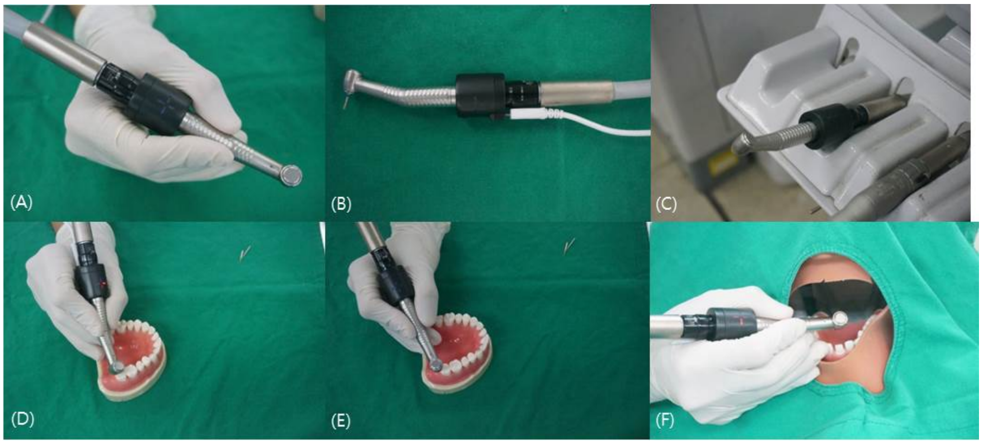


Figure 5.

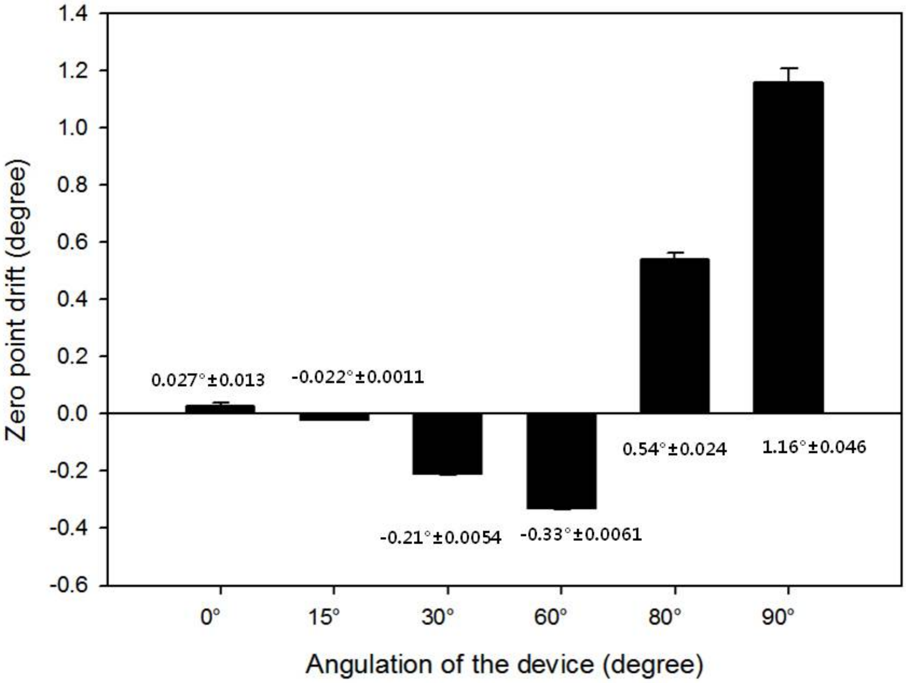


Figure 6.

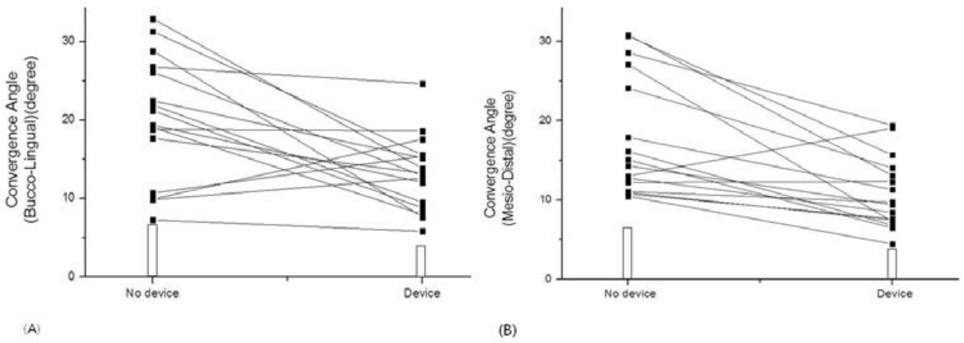


Figure 7.

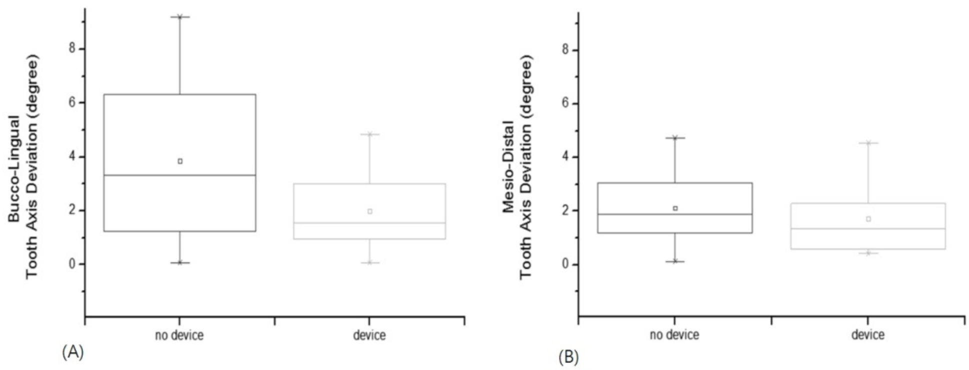
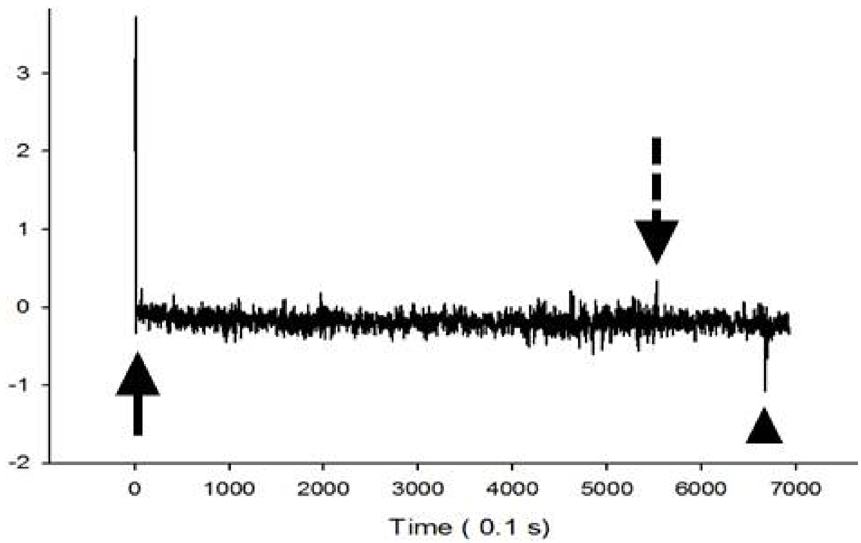


Figure 8.



Tables

Table 1. Zero point drift at various angles

	0°	15°	30°	60°	80°	90°
Drift (°)	0.027	−0.022	−0.21	−0.33	0.54	1.16
Standard deviation	0.013	0.0011	0.0054	0.0061	0.024	0.046

* Average zero point drift for x axis after 30 minutes.

Table 2. The effect of correcting device on convergence angle

(A) Convergence angel for bucco−lingual direction

	Average	Standard Deviation	P−value
No device	20.26°	7.85	0.005
Device	13.21°	4.77	

(B) Convergence angel for mesio−distal direction

	Average	Standard Deviation	P−value
No device	17.88°	7.64	0.001
Device	10.79°	4.48	

Table 3. The effect of correcting device on tooth axis deviation

(A) Tooth axis deviation for Mesio−Distal direction

	Average	Standard Deviation	P−value
No device	3.86°	2.99	0.039
Device	2.00°	1.47	

(B) Tooth axis deviation for Mesio−Distal direction

	Average	Standard Deviation	P−value
No device	2.12°	1.32	0.473
Device	1.71°	1.33	

국문초록

치과 핸드피스 드릴의 각도 보정 장치의 개발

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핸드피스의 각도를 정확하고 일정하게 유지하는 것은 치아삭제나 임플란트의 식립 등에 있어서 중요한 요소이다. 고정성 보철물의 적용을 위한 지대치 형성 시 지대치 수렴각의 이상적인 값은 5° 에서 12° 사이로 알려져 있다. 그러나 지난 연구 결과들에 따르면 실제 임상에서 형성된 지대치의 수렴각은 평균 14° 에서 21° 사이였다. 수렴각의 증가는 접착제의 종류에 관계없이 고정성 보철물의 유지력을 감소시키며, 보철물의 탈락은 도재의 파절에 이어 두 번째로 빈번하게 발생하고 있는 보철물 장착 후 문제점이므로, 이에 대한 시정이 필요하다. 이에 본 연구진은 치과용 핸드피스의 각도를 유지하는데 도움을 줄 수 있는 각도 보정 장치를 개발하여 이를 소개하고자 한다.

이 장치의 효과를 검증하기 위해 단일 금관치아와 3 유닛 브릿지를 위한 치아 삭제시 사용하였다.

핸드피스의 각도를 측정하기 위해, gyro sensor, acceleration sensor, Kalman filter algorithm을 사용하였다. Gyro 센서는 각속도를 측정하여 이를 적분한 값으로 기울기를 구할 수 있고, acceleration sensor는 중력에 대한 상대 가속도를 측정하여 기울기를 구할 수 있다. 그러나 gyro센서는 시간이 경과함에 따라 영점의 이동 현상이 발생하는 문제점이 있고, acceleration 센서는 병진운동에 취약하고, 값이 불안정한 문제점이 있다. 이를 보완하기 위해 Kalman filter 알고리즘이 활용되었다. 본 장치는 핸드피스 몸체부에 부착된다. 따라서 핸드피스 몸체의 각도를 드릴부의 각도로 변환하기 위해 특정행렬식을 이용하였다. 다른 종류의 핸드피스에 장착하게 될 때 핸드피스 경부의 꺾어진 각도만 입력하면 되게 하여 다양한 핸드피스에 적용되도록 하였다. Flexible printed circuit board(FPCB)의 사용으로 핸드피스를 둘러싸는 형태의 장치를 제작할 수 있었고, 이를 통해 크기를 최대 26 mm까지로 줄일 수 있었다. 먼저 다양한 각도에서 30분간 정지상태로 기구를 유지하고, 기준점의 이동을 평가하였다. 수렴각과 지대치 장치의 효과를 검증하기 위해 16명의 지원자(14명의 치과대학학생과 2명의 보철과 수련의)가 실험에 참여하였다. 기구 사용의 선후 관계의 영향을 배제하기 위해 실험자를 무작위로 두 그룹 1과 2로 나누고 다른 변인을 통제하였다. 수렴각을 측정하기 위해 각 술자는 하악 제1대구치 레진 인공 치아를 삭제하였고, 이는 3D 스캐너에 의해 스캔되어, 이를 CAD 프로그램으로 분석하였다. 또한 3 유닛 브릿지의 지대치의 치축 간 각도를 측정하기 위해 하악 제1소구치 지대치 모형을 기준으로 하악 제1대구치 레진

인공 치아를 삭제하였으며, 수렴각과 같은 방법으로 스캔하고 분석하였다. 통계학적 분석은 대응표본 T검정을 통해 이루어졌다.

분석결과 이 장치는 처음 30분간 다양한 각도에서 안정적으로 기준점을 유지하였다(편차 1° 미만). 하지만 90° 에서는 30분 후 영점이 1.16° 움직였다. 단일 금관치아에서 협설측 수렴각은 20.26° (SD 7.85)에서 13.21° (SD 4.77), 근원심측 수렴각은 17.88° (SD 7.64)에서 10.79° (4.48)로 줄일 수 있었고, 통계학적으로 모두 유의미한 차이가 있었다. 지대치 치축간 각도는 협설측은 3.86° (SD 2.99)에서 2.00° (SD 1.33), 근원심은 2.12° (SD 1.32)에서 1.71° (SD 1.33)로 줄일 수 있었으며, 근원심에서는 통계학적 유의미한 차이가 없었으나, 협설측으로는 통계학적으로 유의미한 차이가 있었다.

본 연구에서 개발된 치과용 핸드피스 드릴의 각도 보정 장치는 술자의 감각을 보조할 수 있는 장치로, 현재 활발하게 개발되고 있는 navigation surgery의 정확성과 정밀성을 제공함과 동시에 기구의 부피와 작동 과정을 대폭 간소화 하여 술자의 편의성을 확보하였다.

본 장치는 핸드피스가 사용되는 치의학과 구강악안면외과학의 전반적인 분야에서 활용될 수 있을 것으로 기대된다. 먼저 지대치 형성 시, intra-oral surveyor로써 path of insertion을 일치시키는 역할을 하거나, undercut 인지 및 제거, 수렴각의 감소 등에 활용될 수 있다. 또한 하나 혹은 다수의 임플란트 식립 혹은 교정용 브라켓 부착시에 각도를 확인하고, 수정하는 데 유용할 것이다. 뿐만 아니라 치과대학 학생들에게 올바른 각도의 감각을 익히게 하거나, 초보 치과의사의 술식 훈련용 등의 교육적 목적으로도 활용할 수 있을 것이다. 구강 악안면 외과학의 영역에서는 수술 시야가 확보되지 않는 blind surgery 혹은 심미적인 결

과가 중요한 수술 시 활용할 수 있을 것으로 사료된다.

주요어 : Angulation correction device, convergence angle, tooth axis deviation, Gyro sensor

학 번 : 2011-22434

치의학석사 학위논문

치과 핸드피스 드릴의 각도 보정 장치의 개발

Development of angle correction apparatus for dental handpiece drill

2015 년 2 월

서울대학교 치의학대학원

치의학과

남 윤

치과 핸드피스 드릴의 각도 보정 장치의 개발

지도교수 김 성 민

이 논문을 치의학 석사학위논문으로 제출함

2014 년 10 월

서울대학교 대학원

치의학과

남 윤

남 윤의 석사학위논문을 인준함

2015 년 1 월

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Abstract

The preparation of uniform angle of wall is essential in fixed prosthesis. It has been known that the ideal convergence angle for prosthesis is ranged from 5° to 12°. However the average convergence angle formed in clinical field was ranged from 14° ~ 20°. Increase in convergence angle is the major cause of reduced retention and may lead to the adhesive failure, the second most frequently occurring problem in fixed prosthesis.

In this study, we developed a *de novo* detachable angle-correction apparatus for dental handpiece drill which could help preparation of tooth successfully. We would like to introduce its efficiency on full veneer tooth preparation in single crowns and 3-unit bridges.

To measure the angulation of dental handpiece, we utilized gyro sensor, acceleration sensor, and Kalman filter algorithm. Gyro sensor can measure angular velocities to calculate slope of an object by integrating them. Acceleration sensor can also calculate slope of an object by measuring acceleration relative to gravity. However, accuracy of acceleration sensor is vulnerable to translational movement and shows inconsistent values. In case of gyro sensor zero point shifting occurs as the time goes by. To compensate those problems Kalman filter algorhythm is used in this study. The device developed in this study is directly attached to handpiece body thus a

specific matrix equation is used to convert the angle of handpiece body to handpiece drill. Various handpieces can be used in this system by simply put the cervical angle of them.

Converting the angulation of handpiece body to its drill part could be gained by a specific matrix formulation set on two reference points (2° , 6°). Flexible printed circuit board(FPCB)was used to minimize the size of device, improving clinical usefulness; the maximum diameter of this apparatus is 26 mm.

Zero point error, convergence angle, tooth axis deviation analysis were performed to examine the efficiency of de novo detachable angle correction apparatus. We measured angulation values from various angles (0° , 30° , 60° , 80° , 90°) for x-axis in stationary state to evaluate a zero point error of the device.

Sixteen volunteers were recruited to participate in this study. Fourteen of them were dental students (third and fourth grade, school of dentistry, Seoul National University) and two of them were residents in the department of dental prosthetics. They were divided randomly into two groups(group 1, 2). The only difference between these two groups was the point of time of using the device. For the convergence angle investigation, each practitioner performed tooth preparation on mandibular first molar resin tooth. 1.5 mm punch-out on occlusal plane was used as a reference. For the tooth axis deviation, commercially available ideal abutment model of mandibular first premolar tooth was used as a reference. All abutments were scanned by 3D scanner (D700, 3Shape Co.). The convergence angle and tooth axis deviation were analyzed by CAD program (Solidworks 2013, Dassault systems Co.). Statistical analysis was performed using paired t-test. Statistical significance was defined as $P<0.05$ (SPSS 21.0, IBM Co.).

This device successfully maintained stable zero point (less than 1° deviation) at different angles (0°, 30°, 60°, 80°) for the first 30 minutes. However, after 30 minutes, zero point moved for 1.16° at 90°. In single tooth preparation, without this apparatus, the average bucco-lingual (BL) convergence angle was 20.26° (SD 7.85) and the average mesio-distal (MD) convergence angle was 17.88° (SD 7.64). However, using this apparatus improved the average BL convergence angle to 13.21° (SD 4.77) and the average MD convergence angle to 10.79° (SD 4.48). Furthermore, the angle correction device showed a statistically significant effect on reducing convergence angle of both directions regardless of the order of the direction (p = 0.005, 0.001 for bucco-lingual, mesio-distal, respectively).

In addition, in 3-unit bridge tooth axis deviation, without this apparatus, the average BL tooth axis deviation was 3.86° (SD 2.99) and the average MD convergence angle was 2.12° (SD 1.32). However, using this apparatus improved the average BL convergence angle to 2.00° (SD 1.47) and the average MD convergence angle to 1.71° (SD 1.33). The angulation correction device had a statistically

significant effect on reducing BL tooth axis deviation regardless of the order of using the device ($p = 0.039$). Although there was a reduction of tooth axis deviation on MD direction, it was not statistically significant.

The angle correction device developed in this study is capable of guiding practitioner with high accuracy comparable to commercial navigation surgery. However by succinctly minimizing the operative mechanism, volume of the angle correction device is much smaller than any other commercial navigation surgery system.

This device is expected to be widely utilized in the various fields of orofacial surgery. For instance, when a practitioner does abutment preparation, multiple implant placement, or orthodontic bracket attachment the angle correction device will provide accurate guidance to achieve maximal clinical output. In addition, this device can be used to educate and train dental students by helping them to learn the proper sense of angle and position. In the field of OMFS, the angle correction device will help surgeon to maintain a certain degree of precision under the situation having poor visibility or esthetically important surgery.

Keywords ; Angulation correction device, convergence angle, tooth axis deviation, Gyro sensor

Student Number : 2011−22434

Contents

I. Introduction

Today, the needs for precise dental procedure have been increased. In tooth preparation and implant placement which are the two main axes of modern dental procedures, there is a myriad of developments to meet those needs. Accurate dental procedures not only can improve the quality of it but also can reduce the time required, allowing the minimally invasive technique to reduce postoperative complications.[1] The accuracy of angulation is especially emphasized for tooth preparation of full-crown and placement of implant fixture. While functioning, in order to keep them stable on the tooth, the proper resistance and maintenance of abutment form are necessary. The maintenance of cast prosthesis is determined by convergence angle of abutment, contact area, the inner surface roughness of the structure, and so on.[2,3] Among them, the convergence angle is considered as a primary factor and most of all studies have been focusing on it.[4] The definition of convergence angle is 'the angle between opposing axial walls and has been shown to affect crown retention'. It has been known that the optimal convergence angle is ranged from 5° to 12° .[5,6.]

Also, the accuracy of angulation in dental procedure is important for minimizing the adverse effect, assuring best aesthetic result, and maintaining proper oral health. Ideally, the implant should be placed in parallel with other adjacent implants or remaining tooth. This results in the implant to be applied to the vertical occlusal force. In particular, when more than one dental implant has been placed, the angle between implants affects the maintenance of upper prosthesis. A study on the relationship between retention of the prosthesis and inter-implant angle in 24 overdenture wearing patients reported that as inter implant angle was increased, retention of implant overdenture using locator attachment was significantly decreased.[7] In addition, when using the angled abutment to compensate the angulation error, the stress on implant and surrounding bone has been found to be increased. However, the increased stress did not exceed physiological limit.[8] As such, the correct angulation is important in the dental technique, however, using a dental hand piece, there must be a discrepancy between reality and theory. This discrepancy is well-described in the studies about convergence angle of the abutment for casting crowns. Analysis of the convergence angle of the 478 clinically formed abutments reported that the actual average convergence angle was 21° and there was a great variance among the dentists.[9] Other studies also supported that by reporting the average convergence angle ranging from 14° to 20° and this is considerably deviated from the ideal value.[4,10] An increase of convergence angle results in a reduction of the average retention force regardless of the type of cement used.[11] In fixed prosthesis, the most frequently occurring problem was porcelain fracture (16%) and the second frequently occurring problem was adhesive failure(15.1%) due to insufficient retention. This retention problem can be prevented by maintaining the convergence angle in the certain range mentioned above.[12] Technically this problem occurs because most dental procedures using handpiece solely rely on spatial perception of dentist. In particular, due to physiological limitations of the human being, it is very difficult to achieve an ideal angulation in 3-dimensional space and thus most dentists have difficulty in performing ideal procedures. To compensate human error caused by those limitations and improve quality of dental care, it is necessary to develop a guiding device that can objectively measure the angulation of handpiece drill and indicate the measured value accurately. In particular, Implant placement procedure has already reached a level of computer-guided navigation system that implements the preoperative planning, surgical guiding, and optical tracking device.[2,13] Also, there is a method using electromagnetic tracker and a direct surveying apparatus such as Parallel-A-prep.[14,15] Despite these technical advances, there are many challenges to overcome in order to use computer guided navigation system in clinical field. When a dentist uses surgical guide or optical tracking device, he/she needs to tolerate bulky and expensive hardware with complicated manuals. In addition, errors can occur when applying a surgical guide and optical tracking device. For example, it is practically impossible to guarantee that device can be perfectly suited to all the patients in all surgical situations. According to a previous meta-analysis of 18 studies about accuracy of surgical guide showed that an error at the entry point was 1.07 mm(95% CI : 0.76-1.22 mm) and at the apex 1.63 mm(95% CI : 1.26-2 mm). The mean error in height was 0.43 mm(95% CI : 0.12-0.74 mm) and mean error in angulation was 5.26° (95% CI : 3.94° - 6.58°).[16] Those errors deviated from the ideal value can damage anatomical structures or increase failure rate. According to the authors, there is a large variation of deviation among the studies. Therefore reliability of the computer-guided system is not accurate enough to achieve a 'blind' implantation.[17] In addition, in case of the electromagnetic tracking device, there is a critical limitation; metal prosthesis in oral cavity can cause error. Also, referencing and navigating process itself can be time-consuming.[13] In case of Parallel-A-Prep, mounting procedure is cumbersome and volume of the device is too big. To overcome these limitations and take advantages of computer guided navigation system, it is necessary to develop new device which can reduce interference by minimizing, simplifying the device, is not affected by environmental factors such as a metal prosthesis in oral cavity, can maintain the accuracy of conventional method, is cost-efficient , is intuitive and easy to use, can tolerate high-pressure sterilization process and, is detachable.

In this paper, a *de novo* detachable dental angulation correction device is proposed to overcome the disadvantages of conventional guiding devices and to achieve the requirements listed above. This simple and small device does not have additional compartment such as camera or electromagnetic sensors thus there is no error caused by environmental factors such as metal prosthesis. In addition, because of its small size, it can be attached to the anterior drill−containing part of handpiece, which is rotatable along the axis of the handpiece body. Most importantly, this device does not display angulation of hand piece body but displays angulation of dental drill which is clinically significant. The effectiveness of this device was examined by *in vitro* tooth preparation test using dental phantom® (Nissim type1, Nissan Co.). Full crown preparation is one of the most basic techniques for dentists but level of technique required to achieve the ideal result would be higher than placing implant fixture because it is harder to maintain firm support during the preparation of tooth than implant fixture placement.

II. Materials and Methods

1. Design and Development of the Device

1) Principle of measuring angulation

We used MPU−6050 module (containing gyro sensor and acceleration sensor) commercialized in the field of mobile device and drone for measuring three−dimensional angulation of dental drill. The gyro sensor and acceleration sensor measure angular velocity and relative acceleration of gravity respectively. When integrating the angular velocity measured from the gyro sensor angular deviation can be obtained from the original state. Also, using acceleration sensor, it is possible to measure the extent of the device tilted from the original state by measuring acceleration relative to the gravitational acceleration. Both sensors have complementary pros and cons. Although the stabilized value of the gyro sensor is sensitive to a single rotation, its reliability decreases over time because of the phenomenon called zero point shifting. In the contrary, acceleration sensor shows no zero point drift with the lapse of time but its accuracy is venerable to translational movement. To compensate errors caused by those technical limitations, several algorithms such as the Kalman filter have been applied.[17] For the device developed in this study, gyro sensor and acceleration sensor are simultaneously utilized to calculate angle of the drill with applying Kalman filter algorithm.

2) Computation & display process

The computational process of the device can be divided into three. The first process is to set the reference angulation. This process begins with contacting the tip of drill with tooth surface; at the contact point, practitioner press the pedal with free foot to save the spatial angle of the sensor called reference angulation.

After saving the reference angle, the second process is to translate three axial angles of the handpiece body to those of dental drill. Almost all the commercially available hand pieces have drill-containing head part that is not parallel to hand-holding body part. When the angle between the head and body portion of the hand piece is "θ", the angle between one line that is perpendicular to the sensor and another line that is extended from the axis of drill is also "θ" (Fig 1a).

Therefore, as depicted in figure 1b and 1c, specific formula translates the three axial angles of hand piece body(x', y', z') into those of dental drill(x, y, z). In addition, this process increases clinical efficacy of the device because it is dental drill that grinds the tooth, not the hand piece.

The third process is to track the change in angulation of three axis caused by the rotation of handpiece (from x_1, y_1, z_1 to x_2, y_2, z_2). Since rotation of dental drill along the z-axis does not changes the clinical spatial angle, this device only displays angulation for x– and y– axis. Using this bypass, clinicians can exclude the error caused by simple positional change of hand and body.

In addition, this device uses two reference points. The first reference point is 2 degree which is set by the author. The LED indicators of each axis flash when the dental drill is out of the tolerable angular change (2 degree for each reverse axis). If the handpiece drill is located in the first reference position the LED indicators are automatically switched off.

Therefore, the clinician is able to constantly obtain original angulation when he/she tilt the drill according to the flashing LED indicators. For instance, when the drill is tilted toward +x direction for 3 degree, the LED indicator of −x will blink. If clinician adjusts the angulation by tilting drill toward −x direction, the LED indicator for −x will be turned off. The indicators for x,y aixs of dental drill operate independently. The second reference point is 6 degree which is set by the author. The LED indicator for each axis are going to be turned on constantly when the dental drill moved out of the second reference angle (6 degree) for each reverse axis. For example, when the drill is tilted toward +x direction for 10 degree, the LED indicator of −x will be turned on. If clinician adjusts the angulation the dental drill to the right position, it will be turned off or blinked.

3) Software

Every software for this device use arduino 1.0.1. Source code of the Kalman filter algorithm is described in ardunino forum(http://forum.arduino.cc/)

4) Use of flexible electronic circuit board (fPCB)

This device utilizes flexible PCB and this material helps to dramatically reduce the size and thickness of the device and improve clinical efficacy (Fig 2). To comfortably grab this device within the space between the index finger and thumb, the maximum diameter of the apparatus should be less than 26 mm.

2. The effectiveness and efficacy of device

1) Zero point drift

To evaluate a zero point drift of the device, we measured x angulation values from various angles(0° , 30° , 60° , 80° , 90°) when the device is in the stationary state. Data were collected for 30 minutes. According to *in vitro* studies, the minimum security distance was recommended as 1 mm.[18-20] The '30 minutes' criteria was made to simulate enough time for each daily dental practices. Thus, in this study, we defined the stabilized zero point as 'less than 1 mm deviation for 30 mins.'

2) Reduction of convergence angle during single crown preparation

Sixteen volunteers were recruited to participate in the study. Volunteers were composed of fourteen dental students(third and fourth grade of Seoul National University school of dentistry) and two prosthetics residents. They were divided randomly into 2 groups(1, 2). The only difference between these groups is the timing of using the device. Dental simulator® (Nissim type1, Nissan Co.), Dentiform® (PRO2002-UL-SP-FEM-28, Nissan Co.), #36 tooth model® (A5A-200, Nissan Co.) were used.

When the volunteers used the apparatus, they made 1.5 mm-deep punch out (reference angulation), which was parallel to personally preferred tooth axis at the center of occlusal plane. According to the instruction of apparatus, the volunteers performed tooth preparation within the range of 2 ° ~ 6 ° deviation from the reference angulation. When they did not use the apparatus, they performed usual tooth preparation for full veneer gold crown without marking reference angulation.

All abutments were scanned by 3D scanner® (D700, 3Shape CO.). The convergence angles were analyzed by CAD program® (Solidworks 2013, Dassault systems Co.). The midlines of each axial wall were selected to measure convergence angle. Data were statistically analyzed by paired t-test(α=0.05). SPSS Statistics 21.0® (IBM Co.) was used.

3) Reduction of convergence angle during 3-unit bridge crown preparation

Sixteen volunteers were recruited to participate in the study. Volunteers were composed of fourteen dental students (third and fourth grade of Seoul National University, School of dentistry) and two prosthetics residents. They were randomly divided into 2 groups(First, Later). The only difference between these two groups is the timing of using device. Dental simulator® (Nissim type1, Nissan Co.), Dentiform® (PRO2002-UL-SP-FEM-28, Nissan Co.), #36 tooth model(A5A-200, Nissan Co.), #34 ideal abutment model® (A21A-LL42, Nissan Co.) were used to mimic the real clinical situations.

The axial walls of #34 ideal abutment teeth were used as a reference. When the volunteers used the apparatus, according to instruction of the apparatus, they performed tooth preparation within the range of 6° deviated from the reference angulation. When the volunteers did not use the apparatus, they performed usual tooth preparation for 3-unit bridge prosthesis without setting reference point.

All abutments were scanned by 3D scanner(D700, 3Shape Co.). The convergence angles were analyzed by CAD program(Solidworks 2013, Dassault systems Co.). When observed from fixed point of view, the line between the centers of gravity at the top and bottom surface was defined as tooth axis. By measuring the discrepancy between those points, and height of abutment, we could obtain tooth axis angulation for each directions (Fig 3). To analyze tooth axis deviation, we measured the angle between tooth axes of #34 and #36 abutments. Data were statistically analyzed by paired t-test(α=0.05). SPSS Statistics 21.0®(IBM Co.) was used.

III. Result

1) Device

The maximum diameter is 26 mm. Figure.4 shows appearance and operation of the device (Fig 4). There are two reference points : 2 ° (blink) and 6 ° (constantly turn on). When the angulation of the drill deviate from the reference for 2 ° , the LED indicator of the opposite direction(same axis) blinks. The practitioner should tilt the handpiece drill toward the direction which LED indicator blinks. The LED indicators of different axis operate independently. Since the z-axis is parallel with the drill, one can ignore rotation along it. Therefore, despite of angle adjustment in 3-dimensional space, there are only 2 directions to adjust.

2) Zero point drift

For the first 30 minutes, a *de novo* angle correction device successfully maintained stable zero point (less than 1° deviation) at the four different angles (0° , 30° , 60° , 80°). We measured the angle of 3 axes at every 0.1 second. According to the previous *in vitro* studies, the minimum distance recommended for implant surgical guide to prevent the damage of anatomical structures is 1 mm.[18-20] For wider clinical application, we used the same criterion for our device. Figure 5 showed average zero point movement after 30 minutes. However, after 30 minutes, zero point moved for 1.16° at 90° (SD 0.046). Figure 5 showed average zero point drift after 30 minutes(Table 1).

3) Convergence angle

When not using the apparatus, the average bucco-lingual convergence angle was 20.26° (SD 7.85) and the average mesio-distal convergence angle was 17.88° (SD 7.64). When using the apparatus, the average bucco-lingual convergence angle was 13.21° (SD 4.77) and the average mesio-distal convergence angle was 10.79° (SD 4.48). The angle correction device showed a statistically significant effect on reducing convergence angle for both directions regardless of the order of the direction ($p = 0.005$, 0.001 for bucco-lingual, mesio-distal, respectively)(Fig 6)(Table 2).

4) Tooth axis deviation between 3-unit bridge abutments

When not using the apparatus, the average bucco-lingual tooth axis deviation was 3.86° (SD 2.99) and the average mesio-distal convergence angle was 2.12° (SD 1.32). When using the device, the average bucco-lingual convergence angle was

2.00° (SD 1.47) and the average mesio-distal convergence angle was 1.71° (SD 1.33). The angulation correction device had a statistically significant effect on reducing bucco-lingual tooth axis deviation regardless of the order of using the device ($p = 0.039$). Although there was a reduction of tooth axis deviation on mesio-distal side, it was not statistically significant (Fig.7) (Table 3).

IV. Discussion

In this study, cylinder-shaped hollow detachable angle correction device was developed, and this device was tested on tooth preparation for full veneer and 3 unit-bridge prosthesis. Recently, several attempts of utilizing gyro sensor, acceleration sensor on dental handpiece have been made.[21,22] However, those projects were just conceptual and thus not commercialized because of numerous technical and clinical hurdles. First, the size of devices was not compact enough to use, and secondly, the sensors were only able to detect the angle of handpiece body, not the drill. Another main purpose of this study is to minimize inevitable human errors in various types of tooth preparation with sensor-mounted devices. In this aspect, this study is expected to prospect the field of improving technical accuracy in various types of dental practice.

Convergence angle of abutment largely affects the retention of restorative materials. Convergence angle can be defined as "the angle between opposing axial walls" and has been showned to affect crown retention and it also has been known that the increase of convergence angle reduces retentive force regardless of the types of cement.[5,11] In case of fixed prosthesis, the second most frequently occurring problems is adhesive failure of prosthesis due to insufficient retention, and this problem can be prevented by simply increasing convergence angle. [12]

Using gyro sensor, angular velocity was recorded and this value is integrated to measure rotational angle. In case of conventional devices that have been using this mechanism, accumulated error causes the drift of zero point. In contrast, acceleration sensor detects relative acceleration corresponding with gravitational acceleration and thus the drift of zero point is negligible but has problems with obtaining the slope since its accuracy is venerable to external force and translational movement. To compensate these errors filtering algorithms such as the Kalman filter algorithm and compensatory filter algorithm were developed.[17] In this study zero point shift at various angles (0°, 30°, 60°, 80°, 90°) were observed. To mimic the clinical condition all the data were collected for 30 minutes. Zero point shift less than 1 degree, proved as the minimum error for implant guide surgery in the previous studies, was set as standard.[18-20] The result showed that there was no zero point shift observed except when the device was placed at 90° for 30 minutes. However, this shift is clinically negligible because maintaining handpiece in perpendicular position for 30 min without any movement does not likely occur. The zero point shift measured in this study were time-dependent average values but the raw data showed a outranged value deviated from zero point for an instant moment(0.1s)(Fig 8). However, this outranged value can be considered as spontaneous noise thus it can be said that there was no problem with maintaining zero point value.

The practitioner group using the device developed in this study showed significantly decreased convergence angle (MD p=0.001, BL p = 0.005). For the practitioner group using conventional handpiece, convergence angle values were MD 17.88°, BL 20.26°, close to the value from the previous researches 21°, 14° ~ 20°.[4,10] Another advantage from using this device is improved consistency; distribution of data collected in each trial was decreased from MD 7.64°, BL 7.85° to MD 4.48°, BL 4.77°. For the #36 single crown full veneer preparation there was significant decrease in both average convergence angle and distribution at bucco-lingual and mesio-distal sides. This suggests that the device actually improves not only accuracy but also precision of practitioner's work thus guarantees more credible result.

In case of preparation for 3-unit bridge prosthesis, axis of #34 tooth was set as standard for the preparation of #36 tooth. After that, angle between axis of each abutment was measured. For the bucco-lingual side, the average angle between two axis was decreased from 3.86° (SD 2.99) to 2.12° (SD 1.32) with statistical significance (p=0.039).

In case of the preparation for 3-unit bridge prosthesis, angle between two axes was decreased from 2.00° (SD 1.47) to 1.71° (SD 1.33) at mesio-distal side, but this change was not statistically significant (p = 0.473). Two possible explanations can be discussed here; first, it is easier for practitioner to perform surgical procedures with better accuracy at mesio−distal side than bucco−lingual side. In the previous studies showed the fact that experienced surgeons had significantly less error in bucco−lingual angulation.[23] Based on this result, it is possible to deduce that surgical procedure on mesio−distal side requires less level of technical difficulty than bucco−lingual side and this difference is due to the caused by arrangement of teeth. Therefore, improvement of clinical efficacy by using this device is less dramatic at mesio−distal side. Secondly, since the mesio−distal length of mandibular molar is longer than bucco−lingual length of it, the same 0.5~1 mm preparation of different sides of teeth might have resulted less amount of axial movement at mesio−distal side. Less amount of axial movement caused less difference in angle between the two axes and thus the value became statistically insignificant.

In this study a device that can recognize and save the angle of handpiece drill is developed and the angle data collected from this device can be integrated and displayed to improve practitioner' s accuracy in his/her dental procedure. The clinical efficacy of this device was tested in dental simulator considering various clinical aspects. However, the data collected from the test cannot perfectly reflect real clinical situations because patient' s head and mandible are not fixed as in the dental simulator. Therefore the next generation of this device should be attachable to relatively fixed anatomical structure of patient. In addition, considering the fact that the angle detection by gyro sensor and acceleration sensor is venerable to external force such as tremor, use of vibration−proof materials on this device for low speed handpeice or implant drill is highly recommended.

V. Conclusion

In this study, We developed a *de novo* detachable angle-correction apparatus for dental handpiece drill which has minimized volume and improved convenience. The device maintained stable zero point at various different angles, except 90°. When the practitioners used the device, there were significant reductions of convergence angle of single crown abutment for both directions. ($p = 0.005$, 0.001 for BL, MD, respectively). When the practitioners used the device, there were significant reductions of tooth axis deviation of 3-unit bridge abutment for BL direction.($p = 0.039$). This device can be utilized at various fields of dentistry such as tooth preparation, implant placement, orthodontics, education for novice dental students. In addition, This device can be utilized in the field of oral and maxillfacial surgery, such as implant placement, blind surgery, esthetic surgery

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Figure legends

Figure 1. (A) Angled configuration of the handpiece. When the angle between the head and body portion of the hand piece is "θ", the angle between one line that is perpendicular to the sensor and another line that is extended from the axis of drill is also "θ".
(B, C) Body to head transition matrix formula translates the three axial angles of hand piece body(x', y', z') into those of dental drill(x, y, z). Because of this formula, we don' t have to make different electric circuit board for every different type of handpiece. Since it is dental drill that grinds the tooth, not the hand piece, this process improves clinical efficacy of the device.

Figure 2. At first, an experimental electric circuit was tested on the bread board(A), and then it was printed on normal printed circuit board(PCB)(B). By using bending property of flexible PCB, the device could be rolled around the handpiece. This dramatically reduced the diameter of the device(from 46 mm to 26 mm). According to the spatial coordination of the circuit board, 3D model and prototype were made(C,D).

Figure 3. The Definition of tooth axis (A), tooth height (B), and Tooth axis angulation (C).

(A) When observed from fixed view point, the line between the centers of gravity at the top(red spot) and bottom(y) surface was defined as tooth axis of abutment. When the center of gravity of the top and bottom surface is (x_t, y_t, z_t), and (x_b, y_b, z_b),

then, tooth axis is

$$\overrightarrow{Axis} = (x_t - x_b, y_t - x_b, z_t - z_b)$$

(B) We defined the height of the abutment as the distance from the upper abutment margin to bucco-mesial cusp tip.

(C) Using inverse tangent function, we could obtain tooth axis angulation for each directions.

Figure 4. An angulation correcting device is mounted to the hand piece (top view : A), it is mounted to the hand piece (side view : B), Practitioner could place device attached-hand piece in the cradle (C), the drill' s -X deviation from the reference(D), a regression to the reference, all LED indicators were turned off at reference angle(E), example of actual use (F)

Figure 5. Zero point drift after 30minutes at various angle, showing average zero point drift after 30minutes at different angle of the device. At five different angles (0° , 15° ,30° ,60° , 80°), the zero point drift was less than 1° . The 1° deviation criteria for correcting device is recommended from previous *in vitro* studies.

However, at 90° , the average zero point drift exceeded 1° deviation(1.16°).

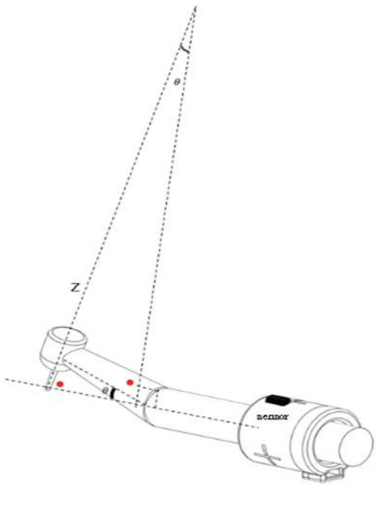
Figure 6. The effect of correcting device on convergence angle for bucco-lingual direction(A) and mesio-distal direction(B).

Figure 7. The effect of correcting device on tooth axis deviation for bucco-lingual direction(A) and mesio-distal direction(B).

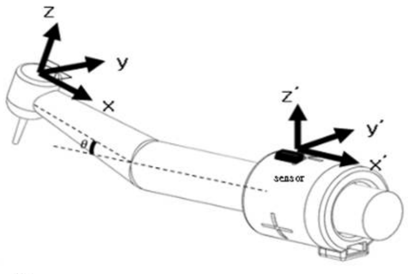
Figure 8. The law data of zero point angle of x-axis at 30° for 10 minutes, showing the drift of zero point during 699 seconds t 30 degree. There are three arrows(full line arrow, dotted line arrow, arrow head) which indicate outranged values. The full line arrow shows ‘zero point adjustment process’ which is always occurred at the beginning of the device operation. It spends less than 1 second. There were other outranged values for an instant moment(0.1s)(dotted line arrow and arrow head). However, this outranged value was considered as a spontaneous noise because it didn’t induce any problem with maintaining zero point value.

Figures

Figure 1.



(A)



(B)

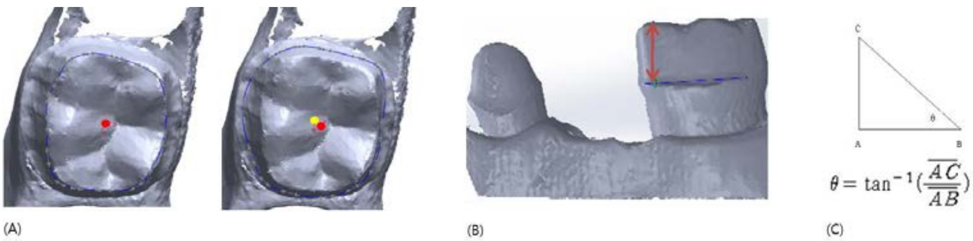
$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

(C)

Figure 2.

(A) (B) (C) (D)

Figure 3.



(A) (B) (C)

Figure 4

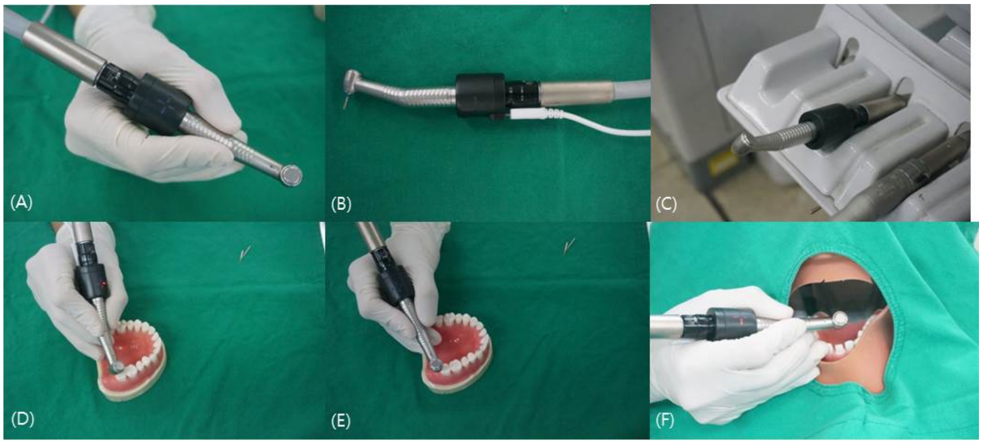


Figure 5.

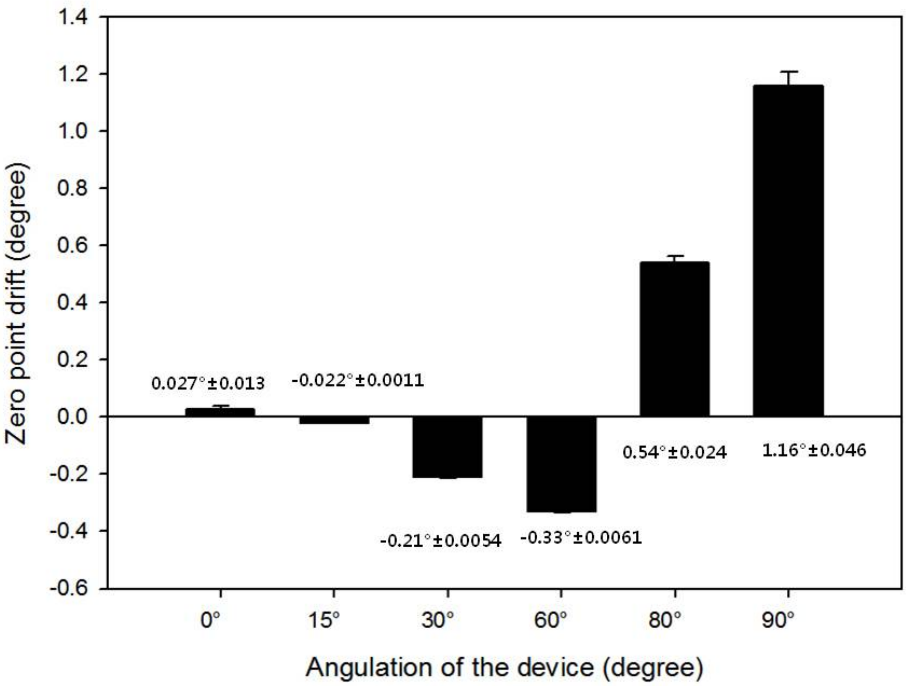


Figure 6.

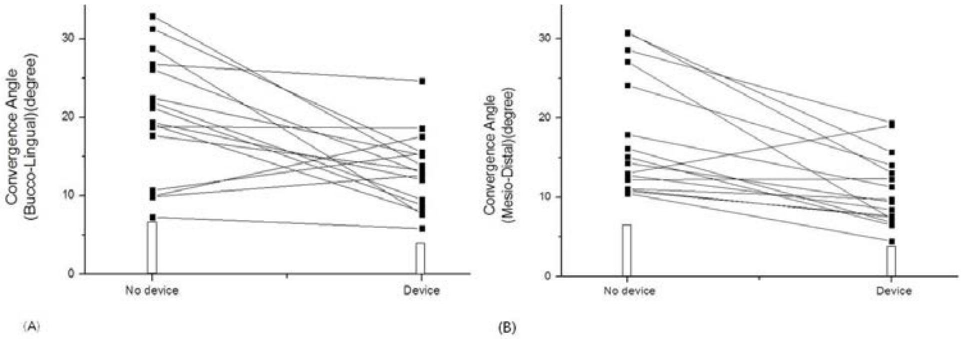


Figure 7.

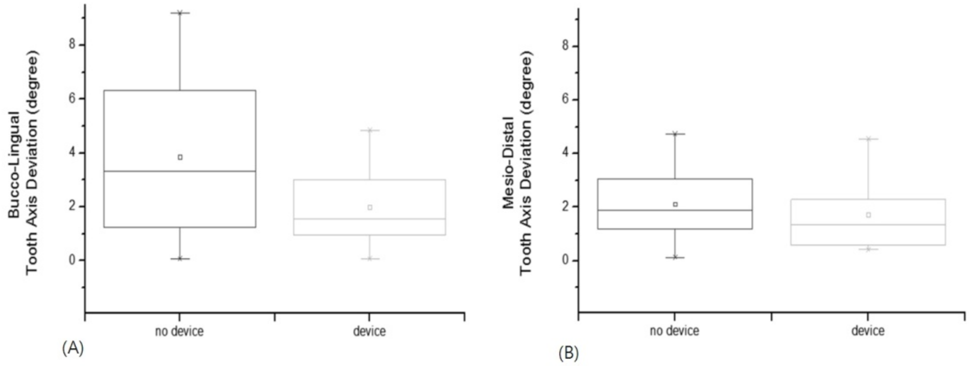
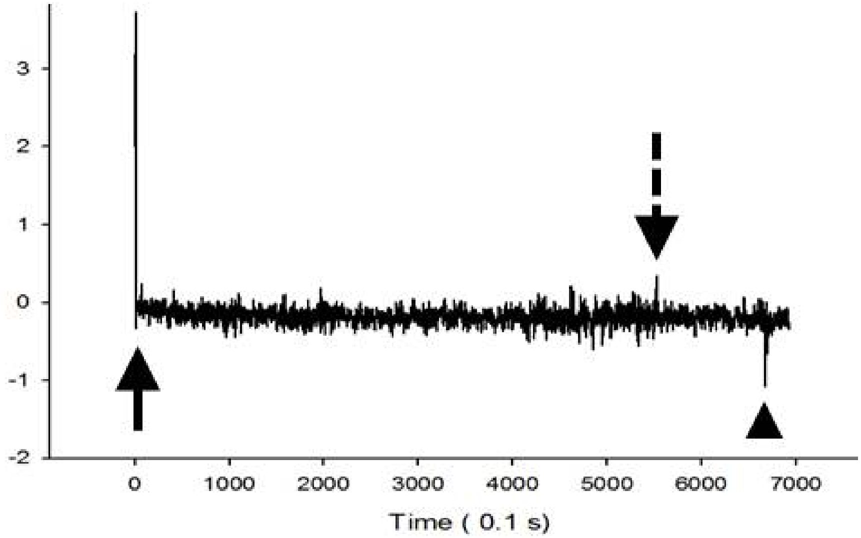


Figure 8.



Tables

Table 1. Zero point drift at various angles

	0˚	15˚	30˚	60˚	80˚	90˚
Drift (˚)	0.027	−0.022	−0.21	−0.33	0.54	1.16
Standard deviation	0.013	0.0011	0.0054	0.0061	0.024	0.046

* Average zero point drift for x axis after 30 minutes.

Table 2. The effect of correcting device on convergence angle

(A) Convergence angel for bucco−lingual direction

	Average	Standard Deviation	P−value
No device	20.26˚	7.85	0.005
Device	13.21˚	4.77	

(B) Convergence angel for mesio−distal direction

	Average	Standard Deviation	P−value
No device	17.88˚	7.64	0.001
Device	10.79˚	4.48	

Table 3. The effect of correcting device on tooth axis deviation

(A) Tooth axis deviation for Mesio−Distal direction

	Average	Standard Deviation	P−value
No device	3.86˚	2.99	0.039
Device	2.00˚	1.47	

(B) Tooth axis deviation for Mesio−Distal direction

	Average	Standard Deviation	P−value
No device	2.12˚	1.32	0.473
Device	1.71˚	1.33	

국문초록

치과 핸드피스 드릴의 각도 보정 장치의 개발

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핸드피스의 각도를 정확하고 일정하게 유지하는 것은 치아삭제나 임플란트의 식립 등에 있어서 중요한 요소이다. 고정성 보철물의 적용을 위한 지대치 형성 시 지대치 수렴각의 이상적인 값은 5° 에서 12° 사이로 알려져 있다. 그러나 지난 연구 결과들에 따르면 실제 임상에서 형성된 지대치의 수렴각은 평균 14° 에서 21° 사이였다. 수렴각의 증가는 접착제의 종류에 관계없이 고정성 보철물의 유지력을 감소시키며, 보철물의 탈락은 도재의 파절에 이어 두 번째로 빈번하게 발생하고 있는 보철물 장착 후 문제점이므로, 이에 대한 시정이 필요하다. 이에 본 연구진은 치과용 핸드피스의 각도를 유지하는데 도움을 줄 수 있는 각도 보정 장치를 개발하여 이를 소개하고자 한다.

이 장치의 효과를 검증하기 위해 단일 금관치아와 3 유닛 브릿지를 위한 치아 삭제시 사용하였다.

핸드피스의 각도를 측정하기 위해, gyro sensor, acceleration sensor, Kalman filter algorithm을 사용하였다. Gyro 센서는 각속도를 측정하여 이를 적분한 값으로 기울기를 구할 수 있고, acceleration sensor는 중력에 대한 상대 가속도를 측정하여 기울기를 구할 수 있다. 그러나 gyro센서는 시간이 경과함에 따라 영점의 이동 현상이 발생하는 문제점이 있고, acceleration 센서는 병진운동에 취약하고, 값이 불안정한 문제점이 있다. 이를 보완하기 위해 Kalman filter 알고리즘이 활용되었다. 본 장치는 핸드피스 몸체부에 부착된다. 따라서 핸드피스 몸체의 각도를 드릴부의 각도로 변환하기 위해 특정행렬식을 이용하였다. 다른 종류의 핸드피스에 장착하게 될 때 핸드피스 경부의 꺾어진 각도만 입력하면 되게 하여 다양한 핸드피스에 적용되도록 하였다. Flexible printed circuit board(FPCB)의 사용으로 핸드피스를 둘러싸는 형태의 장치를 제작할 수 있었고, 이를 통해 크기를 최대 26 mm까지로 줄일 수 있었다. 먼저 다양한 각도에서 30분간 정지상태로 기구를 유지하고, 기준점의 이동을 평가하였다. 수렴각과 지대치 장치의 효과를 검증하기 위해 16명의 지원자(14명의 치과대학학생과 2명의 보철과 수련의)가 실험에 참여하였다. 기구 사용의 선후 관계의 영향을 배제하기 위해 실험자를 무작위로 두 그룹 1과 2로 나누고 다른 변인을 통제하였다. 수렴각을 측정하기 위해 각 술자는 하악 제1대구치 레진 인공 치아를 삭제하였고, 이는 3D 스캐너에 의해 스캔되어, 이를 CAD 프로그램으로 분석하였다. 또한 3 유닛 브릿지의 지대치의 치축 간 각도를 측정하기 위해 하악 제1소구치 지대치 모형을 기준으로 하악 제1대구치 레진

인공 치아를 삭제하였으며, 수렴각과 같은 방법으로 스캔하고 분석하였다. 통계학적 분석은 대응표본 T검정을 통해 이루어졌다.

분석결과 이 장치는 처음 30분간 다양한 각도에서 안정적으로 기준점을 유지하였다(편차 1° 미만). 하지만 90° 에서는 30분 후 영점이 1.16° 움직였다. 단일 금관치아에서 협설측 수렴각은 20.26° (SD 7.85)에서 13.21° (SD 4.77), 근원심측 수렴각은 17.88° (SD 7.64)에서 10.79° (4.48)로 줄일 수 있었고, 통계학적으로 모두 유의미한 차이가 있었다. 지대치 치축간 각도는 협설측은 3.86° (SD 2.99)에서 2.00° (SD 1.33), 근원심은 2.12° (SD 1.32)에서 1.71° (SD 1.33)로 줄일 수 있었으며, 근원심에서는 통계학적 유의미한 차이가 없었으나, 협설측으로는 통계학적으로 유의미한 차이가 있었다.

본 연구에서 개발된 치과용 핸드피스 드릴의 각도 보정 장치는 술자의 감각을 보조할 수 있는 장치로, 현재 활발하게 개발되고 있는 navigation surgery의 정확성과 정밀성을 제공함과 동시에 기구의 부피와 작동 과정을 대폭 간소화 하여 술자의 편의성을 확보하였다.

본 장치는 핸드피스가 사용되는 치의학과 구강악안면외과학의 전반적인 분야에서 활용될 수 있을 것으로 기대된다. 먼저 지대치 형성시, intra-oral surveyor로써 path of insertion을 일치시키는 역할을 하거나, undercut 인지 및 제거, 수렴각의 감소 등에 활용될 수 있다. 또한 하나 혹은 다수의 임플란트 식립 혹은 교정용 브라켓 부착시에 각도를 확인하고, 수정하는 데 유용할 것이다. 뿐만 아니라 치과대학 학생들에게 올바른 각도의 감각을 익히게 하거나, 초보 치과의사의 술식 훈련용 등의 교육적 목적으로도 활용할 수 있을 것이다. 구강 악안면 외과학의 영역에서는 수술 시야가 확보되지 않는 blind surgery 혹은 심미적인 결

과가 중요한 수술 시 활용할 수 있을 것으로 사료된다.

주요어 : Angulation correction device, convergence angle, tooth axis deviation, Gyro sensor

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