Preliminary testing for reduction of insertion torque of orthodontic mini-screw implant using diamond-like carbon films

C Jongwannasiri1,2, T Charasseangpaisarn2 and S Watanabe3

1 King Mongkut’s University of Technology Thonburi (Ratchaburi Learning Park), Ratchaburi 70150, Thailand
2 Department of Prosthodontics, College of Dental Medicine, Rangsit University, Pathum Thani 12000, Thailand
3 Department of Applied Chemistry, Faculty of Fundamental Engineering, Nippon Institute of Technology, Saitama 345-8501, Japan

*Corresponding author’s E-mail address: chavin.jon@kmutt.ac.th

Abstract. Nowadays, titanium alloy is widely used as orthodontic mini-screw implants due to its suitable mechanical properties and excellence in biocompatibility. However, the excessive torques applied during the insertion of orthodontic mini-screw implant can cause necrosis of the surrounding bone. In this article, the insertion torque of orthodontic mini-screw implants is aimed to reduce during treatment by means of surface coating. The three types of coatings, namely, DLC, F-DLC 2:1 and Si-DLC 2:1 coated on orthodontic mini-screw implants were chosen to take into account the insertion torque values compared with uncoated surface. The friction behaviors of the films in ambient air and dry air were assessed using ball-on-disk friction testing. Cytotoxicity tests were performed using MTT assay. The insertion torque values were measured by physiodispenser. The results indicated that, both measured in ambient air and dry air, the addition of F into the DLC films slightly influenced the friction coefficients, while doping with Si strongly influenced the films. These films also exhibited less cytotoxicity on their surfaces. Furthermore, the insertion torque values decreased when coated orthodontic mini-screw implants with F-DLC 2:1 and Si-DLC 2:1 films. Therefore, the F-DLC 2:1 and Si-DLC 2:1 films can be considered to apply on orthodontic mini-screw implant for reducing the insertion torque.

1. Introduction
Over a few decades, commercially pure titanium (CP Ti) is widely used in the field of orthopedic and orthodontic implant materials due to its suitable mechanical properties and excellent biocompatibility [1,2]. However, fatigue strength of CP Ti is lower than that of titanium alloys. Ti-6Al-4V, which widely used as orthodontic mini-screw implants, can be used to overcome this problem [2,3]. Nonetheless, one of the variables that affect the stability of orthodontic mini-screw implants is the maximum insertion torque. Insertion torque is defined as the amount of torque required to overcome the frictional force between the bone and the screw during insertion processes, and is expressed in Newton centimeters (Ncm) [4]. The stability of implants is divided into two terms, namely, primary and secondary stability. The former characterizes the mechanical engagement of the implant after its insertion, whereas the latter is the result of bone regeneration at the implant interface [4,5]. To success
initial stability, a certain value of maximum insertion torque is important [6]. However, many previous studies reported that excessive torques applied during the insertion of orthodontic mini-screw implants can cause necrosis of the surrounding bone, and might impede osseointegration then secondary stability [7,8].

Surface coating is one of the most effective methods to solve this problem. Diamond-like carbon (DLC) films have been extensively studied as potential materials for many tribological applications [9,10]. Furthermore, DLC films doped with fluorine or silicon have shown their excellent tribological properties, exhibiting a very low friction coefficient [11,12]. Consequently, fluorine and silicon incorporated DLC (henceforth denoted F-DLC and Si-DLC, respectively) coated on orthodontic mini-screw implants were aimed to reduce the insertion torque during processes.

2. Experimental details
The schematic of the PBII system and samples preparation before deposition process were previously described in the literature [13]. The DLC (C2H2), F-DLC (C2H2:CF4) and Si-DLC (C2H2:TMS) films were deposited on a Si wafer, Ti-6Al-4V plate and orthodontic mini-screw implant (Ø1.8 mm and 10 mm in length, OSSTEM IMPLANT Co., Ltd.) using the parameters shown in previous study [14]. The friction behavior was conducted using ball-on-disk friction testing. The tribological tests were performed under dry air (0% RH) and ambient air (40% RH) at room temperature (20˚C) using the same parameters listed in the literature [14]. The cytotoxicity was evaluated using Dulbecco modified eagle medium dilution method. The procedure to characterize the cell viability of the samples was also explained in previous study [15]. The insertion torque of orthodontic mini-screw implant was measured by inserting the implants into the pig jaw (lingual position) using physiodispenser (Implantmed, W&H Dentalwerk Bürmoos GmbH, Austria). For each type of coating, three samples were measured.

3. Results and discussion
A previous study [14] reported that F-DLC and Si-DLC films deposited using a gas flow rate ratio of C2H2:CF4 and C2H2:TMS, respectively, at 2:1 have better tribological properties as compared to those deposited at gas flow rate ratio of 1:1 and 1:2. Therefore, the F-DLC and Si-DLC films at a gas flow rate ratio of C2H2:CF4 and C2H2:TMS at 2:1 (represented F-DLC 2:1 and Si-DLC 2:1) were chosen to deposit and evaluate the cytotoxicity and insertion torque value of the films.

The friction coefficients of the films both measured in ambient air and dry air are shown in figure 1. The results indicated that the DLC and F-DLC 2:1 films showed high friction coefficients, while the Si-DLC 2:1 film exhibited a low friction coefficient when measured in ambient air, as shown in figure 1a. In contrast, when measured in dry air (figure 1b), the low friction coefficients were observed in all films, particularly the Si-DLC 2:1 film presented a very low friction coefficient. The formation of transfer layer on the ball surfaces plays an important role in the reduced friction mechanism of the films. The in-depth details of tribological tests were discussed in the previous literature [14].

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Friction coefficients of the F-DLC 2:1 and Si-DLC 2:1 films compared to DLC measured in ambient air (a) and measured in dry air (b).
A cytotoxicity test is a screening way to assess whether a material has any toxic effect on living cells due to leachable components before using it in a medical device. Figure 2 shows the cytotoxicity of DLC films compared with Ti-6Al-4V, which was proven to be highly biocompatibility [16]. It was clearly seen from figure 2 that there was no difference in the viability of L929 fibroblast cells among the specimens. The L929 fibroblast cells grown on Ti-6Al-4V and DLC films had approximate viabilities between 90% and 110% along the experiment. There was no indication that the DLC films were dissolved or toxic to the L929 fibroblast cells because there was no loss of cell integrity due to the coating. Furthermore, the incorporation of F and Si into DLC films did not influence the biocompatibility of the films.

![Figure 2. The cell viability of DLC films compared with Ti-6Al-4V.](image)

Finally, insertion torque measurement is useful in evaluating and predicting the performance of orthodontic mini-screw implant. It is logical to assume that the reduction of friction force as a result of the decrease in friction coefficient will lead to a significant decrease in insertion torque of the orthodontic mini-screw during implant into the bone. Figure 3 shows the insertion torque values of DLCs coated orthodontic mini-screw implants compared to uncoated Ti-6Al-4V. They were implanted into the different regions of the pig jaw (lingual position) with 0 to 50 Ncm insertion torque. As shown in figure 3, the results indicated that the insertion torque values slightly reduced when coated orthodontic mini-screw implants with DLC films, and mostly reduced with the F-DLC 2:1 and Si-DLC 2:1 coatings compared to uncoated Ti-6Al-4V. Furthermore, no samples had fractured during implantation into the pig jaw. Consequently, both F-DLC 2:1 and Si-DLC 2:1 films can improve the performance of orthodontic mini-screw implant by decreasing the friction coefficients, indicating the reduction in the insertion torque values.

![Figure 3. The insertion torque values which implanted into the pig jaw (lingual position).](image)
4. Conclusion
In this article, the results obtained from a study on the reduction of insertion torque of orthodontic mini-screw implant by means of DLC coatings are reported. The friction coefficient, cytotoxicity and insertion torque of the films were analyzed. The results indicated that, both measured in ambient air and dry air, slightly decrease in the friction coefficients were observed in the F-DLC films, while largely decrease were demonstrated in the Si-DLC films, which were compared with the result of the DLC films. All samples also showed excellent biocompatibility on their surfaces. Furthermore, the addition of F and Si into DLC coated on orthodontic mini-screw implants exhibited better reduction in the insertion torque values. Based on these results, the F-DLC and Si-DLC films can be considered beneficial for improving the performance of orthodontic mini-screw implant. However, the insertion torque results were still preliminary testing. Further investigations are needed.

Acknowledgements
This work was supported by a grant from the King Mongkut’s University of Technology Thonburi (KMUTh) Research Fund.

References
[1] Aparicio C, Gil F J, Fonseca C, Barbosa M and Planell J A 2003 Biomaterials 24 263–73
[2] Latysh V, Krallics G, Alexandrov I and Fodor A 2006 Curr. Appl. Phys. 6 262–6
[3] Hanawa T 2004 Mater. Sci. Eng. C 24 745–52
[4] Trisi P, Perfetti G, Baldoni E, Berardi D, Colagiovanni M and Scogna G 2009 Clin. Oral Implants Res. 20 467–71
[5] Javed F and Romanos G E 2010 J. Dent. 38 612–20
[6] Motoyoshi M, Hirabayashi M, Uemura M and Shimizu N 2006 Clin. Oral Implants Res. 17 109–14
[7] Wawrzinek C, Sommer T and Fischer-Brandies H 2008 J. Orofac. Orthop. 69 121–34
[8] Lee N K and Baek S H 2010 Am. J. Orthod. Dentofacial Orthop. 138 e1–8
[9] Robertson J 2002 Mater. Sci. Eng. R 37 129–281
[10] Singh R A, Yoon E S, Kim H J, Kong H, Park S J and Lee K R 2006 Surf. Coat. Technol. 201 4348–51
[11] Park S J, Lee K R and Ko D H 2004 Tribol. Int. 37 913–21
[12] Rubio-Roy M, Corbella C, Bertran E, Portal S, Polo M C, Pascual E and Andújar J L 2009 Diam. Relat. Mater. 18 923–6
[13] Jongwannasiri C and Watanabe S 2016 Surf. Coat. Technol. 306 200–4
[14] Jongwannasiri C, Yoshida S and Watanabe S 2019 Mater. Sci. Appl. 2019 170–85
[15] Jongwannasiri C, Mooletsadoo N, Khantachawana A, Kaewtatip P and Watanabe S 2012 Adv. Mater. Sci. Eng. 2012 1–8
[16] Lausmaa J, Mattsson L, Rolander U and Kasemo B 1986 Mater. Res. Soc. Symp. Proc. 55 351–9