The Online
ANGLE ORTHODONTIST
An International Journal of Orthodontics and Dentofacial Orthopedics
78th Anniversary 1930-2008

TABLE OF CONTENTS

---

doi: 10.2319/083105-306
***The Angle Orthodontist:* Vol. 76, No. 6, pp. 1041–1046.**

Orthodontic Buccal Tooth Movement by Nickel-Free Titanium-Based Shape Memory and Superelastic Alloy Wire

Akihiro Suzuki;[a] Hiroyasu Kanetaka;[b] Yoshinaka Shimizu;[c] Ryo Tomizuka;[d] Hideki Hosoda;[e] Shuichi Miyazaki;[f] Osamu Okuno;[g] Kaoru Igarashi;[h] Hideo Mitani[i]

ABSTRACT

Objective: To examine the mechanical properties and the usefulness of titanium-niobium-aluminum (Ti-Nb-Al) wire in orthodontic tooth movement as compared with nickel-titanium (Ni-Ti) wire.

Materials and Methods: The load deflection of expansion springs was gauged with an original jig. The gradient of the superelastic region was measured during the unloading process. Expansion springs comprising the two types of alloy wires were applied to upper first molars of rats. The distance between the first molars was measured with micrometer calipers.

Results: The force magnitude of the Ti-Nb-Al expansion spring was lower than that of the Ni-Ti expansion spring over the entire deflection range. The initial force magnitude and the gradient in the superelastic region of the Ti-Nb-Al expansion springs were half those of the Ni-Ti expansion springs. Thus, Ti-Nb-Al expansion springs generated lighter and more continuous force. Tooth movement in the Ni-Ti group proceeded in a stepwise fashion. On the other hand, tooth movement in the Ti-Nb-Al group showed relatively smooth and continuous progression. At 17 days after insertion of expansion springs, there were no significant differences between the Ti-Nb-Al and Ni-Ti groups in the amount of tooth movement.

Conclusions: These results indicate that Ti-Nb-Al wire has excellent mechanical properties for smooth, continuous tooth movement and suggest that Ti-Nb-Al wire may be used as a practical nickel-free shape memory and superelastic alloy wire for orthodontic treatment as a substitute for Ni-Ti wire.

KEY WORDS: Nickel-free shape memory and superelastic alloy, Mechanical properties, Tooth movement, Light continuous force, Rat.

Accepted: December 2005. Submitted: August 2005

INTRODUCTION Return to TOC

Shape memory alloys (SMAs), as typified by nickel-titanium (Ni-Ti) alloy, exhibit the unique properties of shape memory and superelasticity.[1,2] Superelasticity is a phenomenon in which stress value remains fairly constant up to a certain point of wire deformation. At the same time, when deformed wire rebounds, the stress value again remains fairly constant.[3] Since the development of Ni-Ti alloy wire for orthodontic appliances in 1971,[4] this wire has been used widely in orthodontic treatment.[3,5,6]

In orthodontic treatment, optimal force produces efficient tooth movement without discomfort to the patient or causing tissue damage.[7] Such tooth movement is generally considered to be brought on by the light continuous force generated by superelastic wire.[8] Moreover, the shape memory properties of this wire have already been applied in heat-activated wire and are also useful in tooth movement.[9–11]

At present, the Ni-Ti alloy is the only practical SMA in medical use. However, this alloy contains a high proportion of nickel. Ni-Ti wires may thus induce nickel hypersensitivity, and nickel-sensitive patients are recommended to avoid this wire.[12,13] Moreover, recently numerous animal studies concerning the carcinogenicity of nickel have been reported,[14–16] though some early studies suggested that nickel did not give rise to cancer in animals.[17]

Titanium-molybdenum alloy has been used for a nickel-free orthodontic wire. However, this wire does not have shape memory and superelastic property.[18] Biocompatible superelastic alloys lacking nickel have therefore been expected in medical use. To reduce the harmful effects of nickel, various nickel-free shape memory and superelastic alloys have been developed.[19,20] Nickel-free titanium-based SMAs composed of nontoxic elements have been systematically investigated.[21] Titanium-niobium-aluminum (Ti-Nb-Al) alloy,[21] which has the best mechanical performance among these nickel-free shape memory and superelastic alloys, was recently developed as a result of advances in processing technology. The aim of this study was to examine the mechanical properties and the usefulness of Ti-Nb-Al wire in orthodontic tooth movement as compared with Ni-Ti wire.

MATERIALS AND METHODS Return to TOC

Ti-Nb-Al and Ni-Ti Wire

Ti-Nb-Al round wires (73 mol% titanium, 24 mol% niobium, and 3 mol% aluminum) of 0.012-inch diameter were made by Furukawa Techno Material Co Ltd, (Kanagawa, Japan). As a reference material, Ni-Ti round wires of 0.012-inch diameter were obtained (Nitinol, 3M Unitek, Monrovia, Calif).

Load-Deflection Measurement of Expansion Springs

The shape of the standardized expansion spring is shown in Figure 1. An original jig was produced with rat maxilla to gauge the load-deflection relationship of the expansion springs (Figure 1). The original jig was designed based on the assumption that generated force changes according to expansion spring displacement during molar expansion.

A compression test was carried out on the expansion springs with a creep meter (RE2-33005S; Yamaden Corp, Tokyo, Japan) fitted with a 2-kgf compression load cell calibrated in the 200-gf range with an original jig. The test machine was operated at a crosshead speed of 0.05 mm/s, and analogue output signals of load and displacement were passed to a CA-3305 autoanalyzing system (Yamaden Corp). Each compression test was carried out five times, with a new piece of expansion spring for each repetition. Expansion springs were loaded in the buccolingual direction on the original jig and were tested at 26°C.[2]

Evaluation of Load-Deflection Curves

The mechanical properties of the expansion springs were assessed based on the load-deflection curve obtained from the compression test. The force magnitude at a deflection of 2 mm during the unloading process was measured. The E-point was defined as the inflection point between the superelastic region and the elastic region during the unloading process. The gradient of the superelastic region during the unloading process was calculated between the E-point and the point at +0.5 mm deflection from the E-point (Figure 2).[22,23]

Animals

Ten male Wistar rats (6 weeks of age) were used in this study. All rats were housed in cages (2 or 3 rats per cage) in an air-conditioned and lighted environment according to the guidelines for Animal Research of Tohoku University. Before appliance placement, rats were acclimatized for 1 week and were fed a laboratory chow with water. Body weight was recorded and oral and systemic conditions were monitored during the acclimatization and experimental periods.

Tooth Movement in Rats

Both the right and left upper first molars of rats were moved to the buccal with standardized expansion springs.[24] Rats were categorized into two groups: five were fitted with Ti-Nb-Al expansion springs (Ti-Nb-Al group), and five were fitted with Ni-Ti expansion springs (Ni-Ti group).

Tooth Movement Measurement

Precise plaster models were scanned with a flatbed scanner (CanoScan 5200F, Canon, Tokyo, Japan) and were magnified to 1000× by digital imaging software (Photoshop, Adobe systems, San Jose, Calif). Digitized images were printed with a laser printer (microline5200, Oki Electric Industry Co Ltd, Tokyo, Japan) and were traced. Distances between the mesial lingual cusps of the right and left first molars were measured with micrometer calipers, and displacement was calculated.

Statistical Analysis

All data were subjected to two-way analysis of variance followed by Student-Newman-Keuls test and Student's *t*-test. Statistical calculations were carried out by Microsoft Excel 2004 (Microsoft Co, Redmond, Washington).

RESULTS Return to TOC

Load-Deflection Properties of Springs

The load-deflection curves for Ti-Nb-Al and Ni-Ti expansion springs are shown in Figure 3. The force magnitude of Ti-Nb-Al expansion springs was lower than that of Ni-Ti expansion springs over the entire deflection range. The initial force magnitude (load at 2.0 mm deflection during the unloading process of the load-deflection curve) is shown in Table 1. The initial force magnitude of Ti-Nb-Al expansion springs was half that of Ni-Ti expansion springs. Gradients of the superelastic region during the unloading process are shown in Table 1. The gradient in the superelastic region for Ti-Nb-Al expansion springs was half that for Ni-Ti expansion springs.

Health Condition of Rats

Animal weight in each group showed a gradual increase within normal limits. During experimental period, there were no significant pathological changes (ie, metal pigmentation, inflammation, and swelling in the maxillary mucosa).

Tooth Movement

Rat first molars were moved to the buccal by Ti-Nb-Al and Ni-Ti expansion springs. The amount of tooth movement in the Ti-Nb-Al and Ni-Ti groups is shown in Figure 4 and Tables 2 and 3. Tooth movement in the Ni-Ti group showed no significant changes from day 1 to day 10 and from day 14 to day 17. Tooth movement in the Ni-Ti group proceeded in a stepwise fashion. Tooth movement in the Ti-Nb-Al group showed no significant change from day 1 to day 7. Tooth movement in the Ti-Nb-Al group showed relatively smooth, continuous progression. At day 17, after insertion of expansion springs, there were no significant differences between Ti-Nb-Al and Ni-Ti groups regarding amount of tooth movement.

DISCUSSION Return to TOC

Biocompatibility of Ti-Nb-Al Alloy Composing Elements

Titanium is used for many dental applications and instruments, such as orthodontic wires, endodontic files, dental implants, and cast restorations. The popularity of titanium is primarily due to its good mechanical properties, its high corrosion resistance, and its excellent biocompatibility.[25] Niobium has been reported to have good cytocompatibility by in vitro studies.[26,27] There are also many reports about good biocompatibility of this element in animal experiments.[28,29] Although it was mentioned that aluminum might play a role in the pathogenesis of Alzheimer's disease,[30,31] some recent investigations denied this relationship.[32,33] On the other hand, there are few reports about aluminum hypersensitivity.

Load-Deflection Characteristics of Expansion Springs

The unique property of a superelastic alloy is that its curve during the unloading process differs from its curve during the loading process, that is, reversibility has an associated energy loss, or hysteresis.[3,6,34] Because the force during unloading causes tooth movement, the unloading curve must be examined for orthodontic use. The force magnitude at 2 mm deflection for the Ti-Nb-Al expansion spring was about half that for the Ni-Ti expansion spring. Ti-Nb-Al wire thus generates lighter force than does Ni-Ti wire.

The load-deflection curve for superelastic alloy wire has a plateau phase along the deflection of the wire. The Ti-Nb-Al expansion spring exerts a lighter force without substantial attenuation when compared with the Ni-Ti expansion spring. Ti-Nb-Al expansion spring can generate more constant force during application of the wires. The maintenance of initial force has advantages in tooth movement. For these reasons, in the same deflection range, Ti-Nb-Al wire generates lighter and more continuous force than does Ni-Ti wire.

Application to Tooth Movement

The amount of tooth movement on day 1 in the Ni-Ti group was 1.64-fold greater than that in the Ti-Nb-Al group. The difference in tooth movement between the two groups is consistent with the difference in the initial force magnitude of the two expansion springs. Previous experimental studies have confirmed larger displacement immediately after wire application. This larger displacement is explained by the compression of the periodontal tissue space in proportion to the initial force magnitude.[7] Previous histological studies have also shown that the degree of periodontal tissue compression influences the pattern of bone resorption, leading to the pattern of tooth movement.[8,35,36] Moderate compression leads to direct bone resorption in periodontal tissue, and excessive compression leads to undermining bone resorption. Lighter forces are advantageous for tooth movement without inducing tissue damage. Ti-Nb-Al wire, which exhibits small initial displacement, may exert optimal initial force and thus reduce tissue hyalinization.

Time courses of tooth movement showed a smooth, continuous displacement pattern in the Ti-Nb-Al group and a stepwise displacement pattern in the Ni-Ti group. The lag phase in the Ti-Nb-Al group was shorter than in the Ni-Ti group. The difference in displacement pattern may have been caused by differences in bone resorption. Undermining bone resorption delays tooth movement until the bone adjacent to the root can be removed, thus giving a stepwise pattern. On the other hand, direct bone resorption, which is induced by steady compression, results in smooth continuous tooth movement.[8] In the present study, the lighter force generated by the Ti-Nb-Al expansion spring resulted in smooth, continuous tooth movement.

Clinical Advantages

The Ti-Nb-Al alloy is able to exert light continuous force without substantial attenuation. These mechanical properties facilitate torque control from initial treatment stages, thus shortening the treatment period.[18,37,38] Moreover, the use of this alloy in place of Ni-Ti may have clinical advantages for patients such as the extension of treatment intervals and the reduction of pain and invasiveness for periodontal tissue through the use of lighter force.[39]

CONCLUSIONS Return to TOC

- The Ti-Nb-Al expansion spring exerted lighter and more continuous force and facilitated safe and efficient tooth movement.
- The tooth movement pattern was smooth because of the mechanical properties of Ti-Nb-Al alloy.
- The present results suggest that the Ti-Nb-Al wire can be used as a nickel-free shape memory and superelastic alloy as a substitute for Ni-Ti alloy wire for orthodontic treatment.

ACKNOWLEDGMENTS

We wish to thank Mr Kazuhiko Arisumi (Miyagi Prefectural Government, Industrial Technology Institute, Department of Food Biotechnology) for allowing the use of the creep meter system and for technical assistance. We are also grateful to Mr Toshihiro Onodera (Tohoku University Graduate School of Dentistry) for technical assistance.

REFERENCES Return to TOC

1. Nakano H, Satoh K, Norris R, Jin T, Kamegi T, Ishikawa F, Katsura H. Mechanical properties of nickel-titanium alloy wires in three-point bending tests. *Am J Orthod Dentofacial Orthop.* 1999; 115:390–395.

2. Wilkinson PD, Dysart PS, Hood JAA, Herbiosn GP. Load-deflection characteristics of superelastic nickel-titanium orthodontic wires. *Am J Orthod Dentofacial Orthop.* 2002; 121:483–495.

3. Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. *Am J Orthod Dentofacial Orthop.* 1986; 90:1–10.

4. Andreasen GF, Hilleman TB. An evaluation of 55 cobalt substituted Nitinol wire for use in orthodontics. *J Am Dent Assoc.* 1971; 82:1373–1375.

5. Andreasen GF, Barrett RD. A use hypothesis for orthodontics. *Am J Orthod.* 1972; 42:172–177.

6. Burstone CJ, Qin B, Morton JY. Chinise NiTi wire—a new orthodondtic alloy. *Am J Orthod.* 1985; 87:445–452.

7. Burstone CJ. Application of bioengineering to clinical orthodontics. In: Graber TM, Vanarsdall RL Jr, eds. *Orthodontics, Current Principles and Techniques.* 2nd ed. St Louis, Mo: Mosby Inc; 1994:235–267.

8. Profitt WR, Fields HW Jr. The biological basis of orthodontic therapy. In: Profitt WR, Fields HW Jr, eds. *Contemporary Orthodontics.* 3rd ed. St Louis, Mo: Mosby Inc; 2000:296– 325.

9. Gil FJ, Planell JA. Shape memory alloys for medical applications. *Proc Inst Mech Eng [H].* 1998; 212:473–488.

10. Van Moorleghem W, Chandrasekaran M, Reynaerts D, Peirs J, Van Brussel H. Shape memory and superelastic alloys: the new medical materials with growing demand. *Biomed Mater Eng.* 1998; 8:55–60.

11. Mullins WS, Bagby MD, Norman TL. Mechanical behavior of thermo-responsive orthodontic archwires. *Dent Mater.* 1996; 5:308–314.

12. Kim H, Johnson JW. Corrosion of stainless steel, nickel-titanium, coated nickel-titanium, and titanium orthodontic wires. *Angle Orthod.* 1999; 69:39–44.

13. Rahilly G, Price N. Current products and practice. Nickel allergy and orthodontics. *J Orthod.* 2003; 30:171–174.

14. Sivulka DJ. Assessment of respiratory carcinogenicity associated with exposure to metallic nickel: a review. *Regul Toxicol Pharmacol.* 2005; 43:117–133.

15. Sunderman FW Jr. Mechanisms of nickel carcinogenesis. *Scand J Work Environ Health.* 1989; 15:1–12.

16. Chen H, Davidson T, Singleton S, Garrick MD, Costa M. Nickel decreases cellular iron level and converts cytosolic aconitase to iron-regulatory protein 1 in A549 cells. *Toxicol Appl Pharmacol.* 2005; 206:275–287.

17. Davidson T, Chen H, Garrick MD, D'Angelo G, Costa M. Soluble nickel interferes with cellular iron homeostasis. *Mol Cell Biochem.* 2005; 279:157–162.

18. Burstone CJ, Goldberg AJ. Beta titanium: a new orthodontic alloy. *Am J Orthod.* 1980; 77:121–132.

19. Olier P, Chandrasekaran L. Development d'un nouvel alliage superelastique sans nickel pour applications biomedicales. *Materiaux.* 2002:1–4.

20. Sakaguchi N, Niinomi M, Akahori T. Tensile deformation behavior of Ti-Nb-Ta-Zr biomedical alloys. *Mater Trans.* 2004; 45:1113–1119.

21. Fukui Y, Inamura T, Hosoda H, Wakashima K, Miyazaki S. Mechanical properties of a Ti-Nb-Al shape memory alloy. *Mater Trans.* 2004; 45:1077–1082.

22. Yoneyama T, Doi H, Hamanaka H, Noda T, Okamoto Y, Karibe M, Mogi M, Miura F. Evaluation of super-elasticity characteristics of orthodontic Ni-Ti alloy wire [in Japanese]. *Kokubyo Gakkai Zasshi.* 1989; 56:93–101.

23. Shima Y, Otshubo K, Yoneyama T, Soma K. Bending properties of hollow super-elastic Ti-Ni alloy wires and compound wires with other wires inserted. *J Mater Sci Mater Med.* 2002; 13:169–173.

24. Igarashi K, Mitani H, Adach H, Shinoda H. Anchorage and retentive effects of a bisphosphonate (AHBuBP) on tooth movements in rats. *Am J Orthod Dentofacial Orthop.* 1994; 106:279–289.

25. Tschernitschek H, Borchers L, Geurtsen W. Nonalloyed titanium as a bioinert metal—a review. *Quintessence Int.* 2005; 36:523–530.

26. Rogers SD, Howie DW, Graves SE, Pearcy MJ, Haynes DR. In vitro human monocyte response to wear particles of titanium alloy containing vanadium or niobium. *J Bone Joint Surg Br.* 1997; 79:311–315.

27. Niinomi M. Fatigue performance and cyto-toxicity of low rigidity titanium alloy, Ti-29Nb-13Ta-4.6Zr. *Biomaterials.* 2003; 24:2673–2683.

28. Johansson CB, Albrektsson T. A removal torque and histomorphometric study of commercially pure niobium and titanium implants in rabbit bone. *Clin Oral Implants Res.* 1991; 2:24–29.

29. Matsuno H, Yokoyama A, Watari F, Uo M, Kawasaki T. Biocompatibility and osteogenesis of refractory metal implants, titanium, hafnium, niobium, tantalum and rhenium. *Biomaterials.* 2001; 22:1253–1262.

30. Rondeau V, Commenges D, Jacqmin-Gadda H, Dartigues JF. Relation between aluminum concentrations in drinking water and Alzheimer's disease: an 8-year follow-up study. *Am J Epidemiol.* 2000; 152:59–66.

31. McDowell I. Alzheimer's disease: insights from epidemiology. *Aging Clin Exp Res.* 2001; 13:143–162.

32. Shirabe T, Irie K, Uchida M. Autopsy case of aluminum encephalopathy. *Neuropathology.* 2002; 22:206–210.

33. Gupta VB, Anitha S, Hegde ML. et al. Aluminium in Alzheimer's disease: are we still at a crossroad?. *Cell Mol Life Sci.* 2005; 62:143–158.

34. Profitt WR, Fields HW Jr. Mechanical principles in orthodontic force control. In: Profitt WR, Fields HW Jr, eds. *Contemporary Orthodontics.* 3rd ed. St Louis, Mo: Mosby Inc; 2000:326–361.

35. Reitan K. Some factors determining the evaluation of forces in orthodontics. *Am J Ortohd.* 1957; 43:32–45.

36. Reitan K. Tissue behavior during orthodontic tooth movement. *Am J Orthod.* 1960; 46:881–900.

37. Andreasen GF, Barrett RD. An evaluation of cobalt-substituted nitinol wire in orthodontics. *Am J Orthod.* 1973; 63:462–470.

38. Burstone CJ. Variable-modulus orthodontics. *Am J Orthod.* 1981; 80:1–16.

39. Andreasen GF, Morrow RE. Laboratory and clinical analyses of nitinol wire. *Am J Orthod.* 1978; 73:142–151.

TABLES Return to TOC

Table 1. Force Magnitude of 2 mm Deflection and Gradient of Su perelastic Region During the Unloading Process (Mean ± SD)*

	Ti-Nb-Al Springs (n = 5)	Ni-Ti Springs (n = 5)	*P* Value†
Force magnitude (gf)	11.62 ± 2.03	24.34 ± 1.82	<.0001
Gradient (gf/mm)	6.08 ± 1.17	11.64 ± 1.05	<.0001

* Ti-Nb-Al indicates titanium-niobium-aluminum; Ni-Ti; nickel-titanium.

† *P* value indicates probability of unpaired Student's *t*-test.

Table 2. Comparison of Tooth Movement (mm) Between Titanium-Niobium-Aluminum (Ti-Nb-Al) and Nickel-Titanium (Ni-Ti) Groups (Mean ± SD)*

Day	Ti-Nb-Al Group (n = 5)	Ni-Ti Group (n = 5)	*P* Value†
0	0 ± 0	0 ± 0	NS
1	0.57 ± 0.19	0.91 ± 0.14	<.05
3	0.66 ± 0.1	0.92 ± 0.17	<.05
7	0.71 ± 0.14	1.14 ± 0.19	<.01
10	0.94 ± 0.19	1.23 ± 0.25	NS
14	1.28 ± 0.14	1.78 ± 0.32	<.05
17	1.67 ± 0.28	1.9 ± 0.31	NS

* NS indicates not significant.

† *P* value indicates probability of unpaired Student's *t*-test.

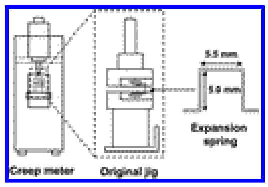
Table 3. Comparison of Tooth Movement (mm) Among Days (Mean ± SD)*

Day	Ti-Nb-Al Group (n = 5)	*P* Value†	Ni-Ti Group (n = 5)	*P* Value
0	0 ± 0		0 ± 0	
1	0.57 ± 0.19	<.01	0.91 ± 0.14	<.01
3	0.66 ± 0.1	NS	0.92 ± 0.17	NS
7	0.71 ± 0.14	NS	1.14 ± 0.19	NS
10	0.94 ± 0.19	<.05	1.23 ± 0.25	NS
14	1.28 ± 0.14	<.01	1.78 ± 0.32	<.01
17	1.67 ± 0.28	<.01	1.9 ± 0.31	NS

* Ti-Nb-Al indicates titanium-niobium-aluminum; Ni-Ti, nickel-titanium; and NS, not significant.

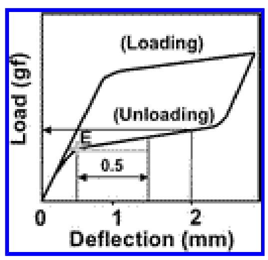
† *P* value indicates probability of Student-Newman-Keuls test.

FIGURES Return to TOC



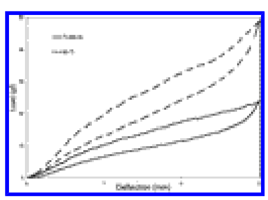
Click on thumbnail for full-sized image.

Figure 1. Schematic view of standardized expansion spring and load-deflection measurement with original jig



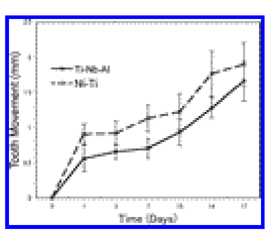
Click on thumbnail for full-sized image.

Figure 2. Evaluation points for load-deflection curve



Click on thumbnail for full-sized image.

Figure 3. Load-deflection curves for titanium-niobium-aluminum and nickel-titanium expansion springs



Click on thumbnail for full-sized image.

Figure 4. Time-courses of tooth movement in titanium-niobium-aluminum and nickel-titanium groups

[a]Graduate student, Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[b]Assistant Professor, Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[c]Assistant Professor, Division of Oral and Craniofacial Anatomy, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[d]Research Fellow, Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[e]Associate Professor, Precision and Intelligence Laboratory, Tokyo Institute of Technology, Yokohama, Japan

[f]Professor, Institute of Materials Science, University of Tsukuba, Tsukuba, Japan

[g]Professor, Division of Dental Biomaterials, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[h]Professor, Division of Oral Dysfunction Science, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

[i]Professor Emeritus, Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, Sendai, Miyagi, Japan

Corresponding author: Dr Hiroyasu Kanetaka, Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, 4-1 Seiryo-machi, Aoba-ku, Sendai 980-8575, Miyagi, Japan (E-mail: kanetaka@mail.tains.tohoku.ac.jp)
