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Surface characteristics and mechanical behavior of retrieved orthodontic microimplants

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Abstract: Objectives: To observe the surface characteristics and mechanical behavior of retrieved microimplants under clinically simulating experimental conditions and to investigate the feasibility of reuse of microimplants. Materials and methods: The microimplants, inserted at different angles, were retrieved from the patients (RMIP) and the artificial bone (RMIA). Surface characteristics, including morphologic changes of tips and thread edges, length reduction, and surface compositional variation, were evaluated using a field emission scanning electron microscope, a stereoscopic microscope, and energy-dispersive X-ray spectroscopy, respectively. Mechanical behavior comprising maximum insertion torque (MIT) and insertion time was tested with the artificial bone under clinically simulating conditions. Results: The tips and thread edges were worn out to various degrees in retrieved microimplants and thin deposits were observed on the surface in the RMIP group. Traces of foreign elements, such as iron, sulphur, and calcium, were detected on the surface of RMIP. Both MIT and insertion time of retrieved microimplants were increased compared to their initial use, and were much greater in RMIP. The increases of MIT were seen in all groups inserted at the insertion angle of 45° compared with 90°, although the differences were not statistically significant. Conclusions: Retrieved microimplants exhibited different degrees of changes on surface characteristics and mechanical behavior, with more changes in RMIP. The reuse of microimplants for immediate relocation in the same patient may be acceptable; however, postponed relocation and allogeneic reuse of microimplants are not recommended in clinical practice.

Key words: Orthodontic microimplant; Surface characteristics; Mechanical behavior; Retrieval analysis
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1 Introduction

Microimplants have been widely used as a skeletal anchorage in orthodontics because of their simplicity in placement and removal, minimal anatomical limitations, and cost-effectiveness (Park et al., 2006). With the advent of the microimplant, the challenging tooth movement in conventional treatment now has become simple and easy. However, clinicians may encounter situations occasionally, in which the microimplant needs to be replaced to a new position. When the microimplant is not positioned properly or in the proximity of roots after placement, positional change and immediate relocation of the microimplant should be considered. Another situation is that when the microimplant obstructs the anticipated tooth movement or fails during treatment, the microimplant needs to be placed into adjacent sites. In addition, the microimplant could be considered for recycling for economic reasons.

The aforementioned situations are all related with the reuse of microimplants, including immediate relocation and postponed relocation. However, it remains controversial whether the reuse of microimplants is sensible and feasible (Mattos et al., 2010; Chung et al., 2014; Estelita et al., 2014; Iijima

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et al., 2015; Noorollahian et al., 2015; Gross et al., 2016). In previous studies, some researchers described their recycling protocols and reported that their methods had no significant negative effects on mechanical strength (Estelita et al., 2014; Noorollahian et al., 2015; Gross et al., 2016), while others did not recommend the reuse of retrieved microimplants because of their altered surface characteristics and changed mechanical properties (Mattos et al., 2010; Chung et al., 2014). The different results might be due to the different sources of retrieved microimplants. The microimplants in the former experiments were retrieved from the artificial bone or the block of pig iliac bone. This situation is similar to the clinical setting, in which microimplants are relocated immediately after their first insertion (Estelita et al., 2014; Noorollahian et al., 2015), while the retrieved microimplants in the latter experiments were clinically used and functioned in an oral environment, similar to the microimplants in the clinical scenario of postponed relocation (Mattos et al., 2010; Chung et al., 2014; Iijima et al., 2015). Thus, we speculated that there was a difference between immediate relocation and postponed relocation, which was derived from various changes of surface characteristics and mechanical properties of the microimplants during their first insertion and during their service as anchorage in orthodontic treatment.

In clinical practice, the placement angulation of microimplants was recommended to reduce the risk of root contacts (Park et al., 2001). However, it is unknown what might be the impact of different insertion angles on surface characteristics and mechanical behavior of retrieved microimplants.

As far as we know, there has been no study comparing the surface characteristics or mechanical behavior between microimplants retrieved from in vitro experiments and from patients, which simulated both immediate and postponed relocation. Also, no study evaluated the surface characteristics or mechanical behavior between the above-mentioned retrieved microimplants inserted at different angles. Therefore, microimplants were retrieved from two sources in this study, one from artificial bone and the other from patients with the same type, and were reinserted at different insertion angles. The purposes of this study were to test the null hypothesis that there is a difference among new microimplants, between retrieved microimplants from artificial bone and retrieved microimplants from patients in surface characteristics and mechanical behavior in clinically simulating experimental conditions, and to investigate the feasibility of microimplant reuse.

2 Materials and methods

The microimplants in this study were retrieved after their successful use in patients, who received orthodontic treatment by the same orthodontist (HSP) from January 2011 to March 2016 at the Department of Orthodontics, School of Dentistry, Kyungpook National University, Korea. Retrieved microimplants were included if: (1) they were implanted from January 2011 to December 2014; (2) the type was SH1312-07 (titanium alloy, tapered type, diameter of 1.3 mm, thread length of 7 mm) with the same design in the three years (AbsoAnchor®, Dentos, Daegu, Korea); (3) the surgical method for microimplant placement was self-drilling; (4) the location for microimplant placement was between the maxillary second premolars and first molars. Retrieved microimplants from patients with diabetes, osteoporosis, or who smoked were excluded. Finally, 40 microimplants from 26 patients, including 12 males and 14 females with age range of 13–53 years, were included and the duration of these microimplants in intraoral environment was more than 8 months ((25.1±9.6) months). The included microimplants were cleaned according to the manufacture's instruction (Dentos, 2014) for later evaluation.

Forty new microimplants (SH1312-07) manufactured in the same lot were used as the control group to guarantee the same design as that of the retrieved ones. They were inserted into a double-layer artificial bone block (Sawbones®, Pacific Research Laboratories Inc., Vashon, Washington, USA), which simulated the maxillary alveolar bone in molar areas. The surficial layer of the bone block was 1.5 mm thick and we chose 50 pcf (pounds per cubic foot) density between 50 and 40 pcf, which are commercially available, to mimic the condition closely for a clinical situation for maxillary buccal alveolar cortical bone. The base layer had a density of 20 pcf, mimicking cancellous bone. Of 40 microimplants, 20 microimplants were inserted at an insertion angle of 45° to the surface of the artificial bone (MIA45) and the other 20 microimplants were inserted at 90° (MIA90). They were all removed immediately after insertion and were grouped as retrieved microimplants from the artificial bone block (RMIA). The whole process of the experiment is shown in Fig. 1.

2.1 Morphology observation and measurement

All microimplants were fixed in the same orientation by a holder (Bimu mini precision parts vice, Tavannes, Switzerland) and were examined with a stereoscopic microscope (Olympus SZX7, Tokyo, Japan). Images of these microimplants, with the magnification of 20 times, were captured and the length between the tip and the neck part (Fig. 2) was measured using ImageJ software (National Institutes of Health (NIH), Bethesda, MD, USA).

The surfaces of microimplants were scanned by a field emission-scanning electron microscope (FE-SEM, Hitachi SU8220, Tokyo, Japan) at 15 kV acceleration voltage. SEM images with a magnification of 100 times were captured for the tip part of microimplants.

2.2 Surface composition analysis

Energy-dispersive X-ray spectroscopy (EDS) was performed to analyze the relative weight percentage of surface elemental composition on the tip part of microimplants using FE-SEM with a magnification of 1000 times at the acceleration voltage of 15 kV and a silicon drift detector (Horiba X-Max^N, Kyoto, Japan).

2.3 Insertion torque and insertion time

The new microimplants were inserted into the artificial bone block as mentioned above at the insertion angles of 45° and 90° (MIA45 and MIA90) using a surgical engine (Elocomed SA200C, W&H, Burmoos, Austria) at a rotational speed of 20 r/min. Once the edge of the last thread touched the surface of the artificial bone, the insertion was stopped. During the insertion process, the torque values were recorded at 1/8 s intervals. The maximum insertion torque (MIT) and insertion time were recorded and calculated to evaluate the mechanical behavior.

After these microimplants were retrieved from the artificial bone block, they were inserted into the bone block again at the same insertion angle as the first time (45° and 90°). The retrieved microimplants from patients were also divided into two subgroups randomly according to a random number table and each subgroup included 20 microimplants. One subgroup was inserted at the insertion angle of 45° (RMIP45) and the other was at 90° (RMIP90). The same torque test parameters were used.

2.4 Statistical analysis

Statistical analyses were performed using SPSS software (Version 23, IBM Corp., Armonk, NY, USA). The Shapiro-Wilk normality test was performed to assess data normality and the Levene test was used for homogeneity of variance. For the residual length of the microimplant, the nonparametric Kruskal-Wallis test was used, followed by a post-hoc analysis with the Mann-Whitney *U*-test. For MIT and insertion time among MIA, RMIAII (retrieved microimplants from the artificial bone were reinserted into the artificial bone), and RMIP, one-way analysis of variance (ANOVA) was used and followed by a post-hoc analysis with the Tukey's test. The independent-samples *t*-test was used to compare MIT and insertion time between different insertion angles (45° vs. 90°). Statistical significance was determined at $P<0.05$.

Sample size was calculated according to a pilot study and at least 24 microimplants retrieved from patients were needed with $\alpha=0.05$, two-tailed, and a power of 80%.

3 Results

3.1 Morphology observation and measurements

The surface morphological changes at the tip and thread edges of microimplants were observed via the SEM images. The topmost part of the control group (Fig. 3a) was relatively sharp, while RMIA90I (Fig. 3c), RMIA45I (Fig. 3d), and RMIP (Fig. 3b) were gradually worn out to different degrees. The thread edges also showed as worn out and there was plastic deformation in the retrieved microimplants. Additionally, some thin deposits were observed at the surface in the RMIP group.

The length reduction of retrieved microimplants was negligible, although a statistically significant difference ($P<0.05$) was seen between the control group ((7.07±0.01) mm) and RMIP ((6.98±0.14) mm) (Table 1).

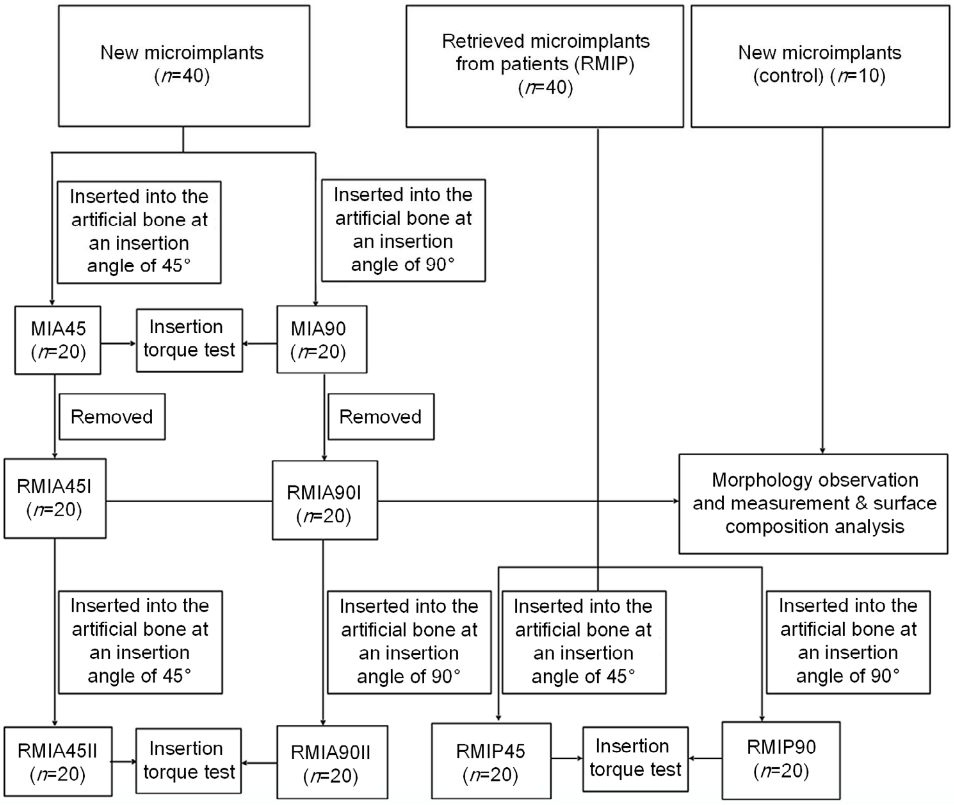

Fig. 1 Flow chart of the experiment process

MIA45, new microimplants were inserted into the artificial bone at an insertion angle of 45°; MIA90, new microimplants were inserted into the artificial bone at an insertion angle of 90°; RMIA45I, retrieved microimplants from the artificial bone with an insertion angle of 45°; RMIA90I, retrieved microimplants from the artificial bone with an insertion angle of 90°; RMIA45II, retrieved microimplants from the artificial bone were reinserted at an insertion angle of 45°; RMIA90II, retrieved microimplants from the artificial bone were reinserted at an insertion angle of 90°; RMIP, retrieved microimplants from patients; RMIP45, retrieved microimplants from patients were reinserted at an insertion angle of 45°; RMIP90, retrieved microimplants from patients were reinserted at an insertion angle of 90°

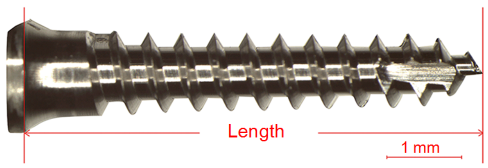

Fig. 2 Measurement specification for the length of the microimplant

Table 1 Residual length measured for three retrieved microimplant groups

Group	Residual length (mm)	Multiple comparison		
		RMIA45I	RMIA90I	RMIP
Control (n=10)	7.07±0.01	0.663	1.000	0.029*
RMIA45I (n=20)	7.01±0.07		1.000	1.000
RMIA90I (n=20)	7.01±0.09			0.142
RMIP (n=40)	6.98±0.14			
P-value	0.015*			

* P<0.05. Data are expressed as mean±standard deviation

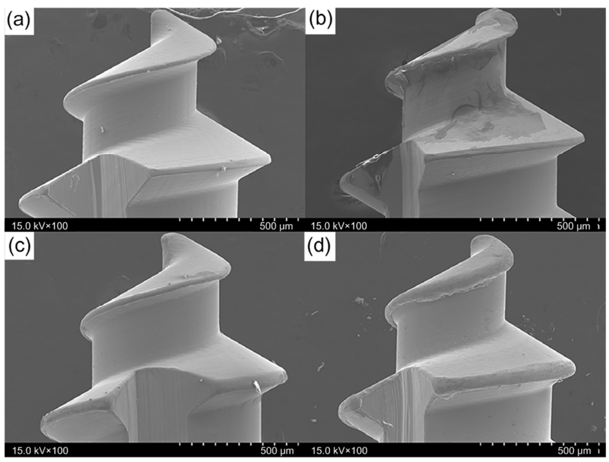

Fig. 3 FE-SEM images for the surface morphological changes of microimplants

(a) New microimplants; (b) RMIP; (c) RMIA90I; (d) RMIA45I

3.2 Surface composition analysis

The surface elemental composition on the tip part of microimplants was analyzed by EDS. Both in the control and RMIAI groups, titanium (Ti), oxygen (O), aluminium (Al), and vanadium (V) were detected (Figs. 4a and 4c). In the RMIP group, in addition to the above elements, traces of iron (Fe), sulphur (S), and calcium (Ca) were detected and the percentage of O increased relatively (Fig. 4b).

3.3 Maximum insertion torque and insertion time

Tables 2 and 3 compared MIT and insertion time among MIA, RMIAII, and RMIP groups, respectively, for insertion at angles of 45° and 90°. The mean MIT values of retrieved microimplants, including RMIAII and RMIP, were both greater than MIA. The mean MIT of RMIP was also larger than that of the corresponding RMIAII group. The mean insertion time increased in the retrieved microimplants compared with MIA. The mean insertion time of RMIP was greater than that of the corresponding RMIAII group.

MITs between different insertion angles (45° vs. 90°) were also compared in the MIA (P=0.188), RMIAII (P=0.864), and RMIP groups (P=0.524); however, no statistically significant difference was found between them. Mean values of insertion time in MIA90 (38.99 s), RMIA90II (39.75 s), and RMIP90 (40.56 s) were greater than MIA45 (35.11 s), RMIA45II (37.00 s), and RMIP45 (38.19 s), respectively (P=0.000).

Figs. 5a and 5b show the representative graphs of insertion torque and insertion time during the insertion process for the MIA, RMIAII, and RMIP groups at the insertion angle of 45° and 90°, respectively.

Table 2 Maximum insertion torque of different microimplant groups inserted at different insertion angles

Angle	Group (n=20)	Maximum insertion torque (Ncm)	P-value[2]	Multiple comparison	
				RMIAII	RMIP
45°	MIA	5.21±0.37	0.188	0.005*	0.000*
	RMIAII	5.63±0.38	0.864		0.000*
	RMIP	6.24±0.47	0.524		
	P-value[1]	0.000*			
90°	MIA	4.98±0.42		0.007*	0.000*
	RMIAII	5.50±0.44			0.001*
	RMIP	6.10±0.66			
	P-value	0.000*			

* P<0.05. Data are expressed as mean±standard deviation. [1] P-value means statistical significance of ANOVA for MIT among MIA, RMIAII, and RMIP. [2] P-value means statistical significance of the independent-samples t-test for MIT between different insertion angles (45° vs. 90°)

Table 3 Insertion time of different microimplant groups inserted at different insertion angles

Angle	Group (n=20)	Insertion time (s)	P-value[2]	Multiple comparison	
				RMIAII	RMIP
45°	MIA	35.11±0.85	0.000*	0.000*	0.000*
	RMIAII	37.00±0.78	0.000*		0.000*
	RMIP	38.19±1.12	0.000*		
	P-value[1]	0.000*			
90°	MIA	38.99±0.73		0.013*	0.000*
	RMIAII	39.75±0.77			0.008*
	RMIP	40.56±0.94			
	P-value	0.000*			

* P<0.05. Data are expressed as mean±standard deviation. [1] P-value means statistical significance of ANOVA for insertion time among MIA, RMIAII, and RMIP. [2] P-value means statistical significance of the independent-samples t-test for insertion time between different insertion angles (45° vs. 90°)

4 Discussion

4.1 Experimental setting

The reuse of microimplants can be different on the basis of different clinical situations, so this study evaluated surface characteristics and mechanical behavior of the microimplants retrieved from two sources to simulate the immediate relocation and postponed relocation in clinically simulating experimental conditions. For the purpose of simulating the clinical setting as far as possible, we used a double-layer artificial bone block, which simulated the maxillary alveolar bone in molar areas (Park et al., 2008). We also chose a rotational speed of 20 r/min during the insertion process, as recommended by the manufacturer (Dentos, 2014). Additionally, considering clinicians commonly place microimplants into the bone at an angle in clinical practice, we set 45° and 90° as different insertion angles.

4.2 Surface characteristics

The SEM images showed that the retrieved microimplants were worn out to some extent after clinical use or laboratory use. With regard to RMIA, although they were just loaded with insertion force and friction during their insertion and removal processes, slight wear deformation was still found on the

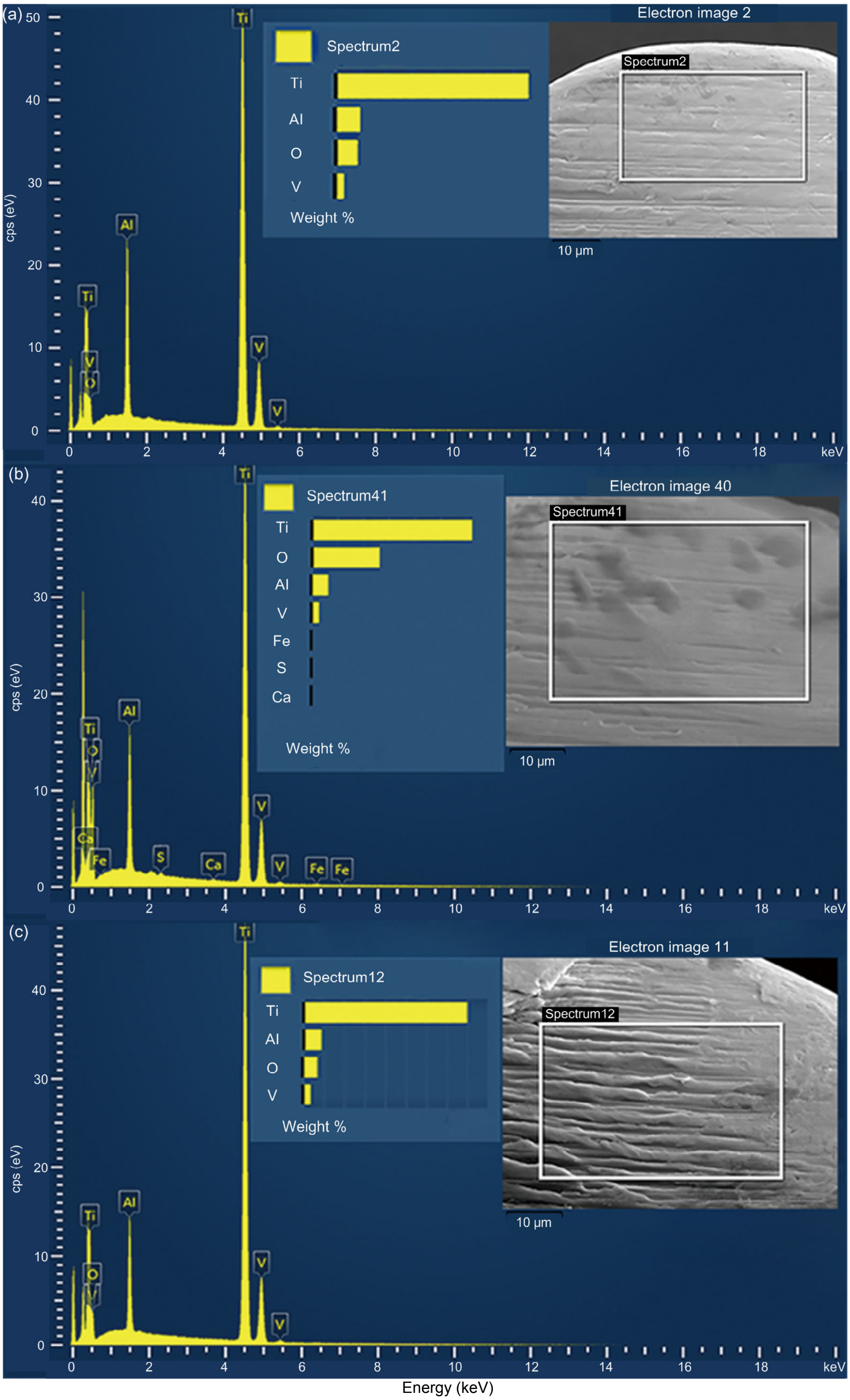

Fig. 4 Surface element analysis of microimplants

(a) New microimplants; (b) RMIP; (c) RMIAI. cps: counts per second

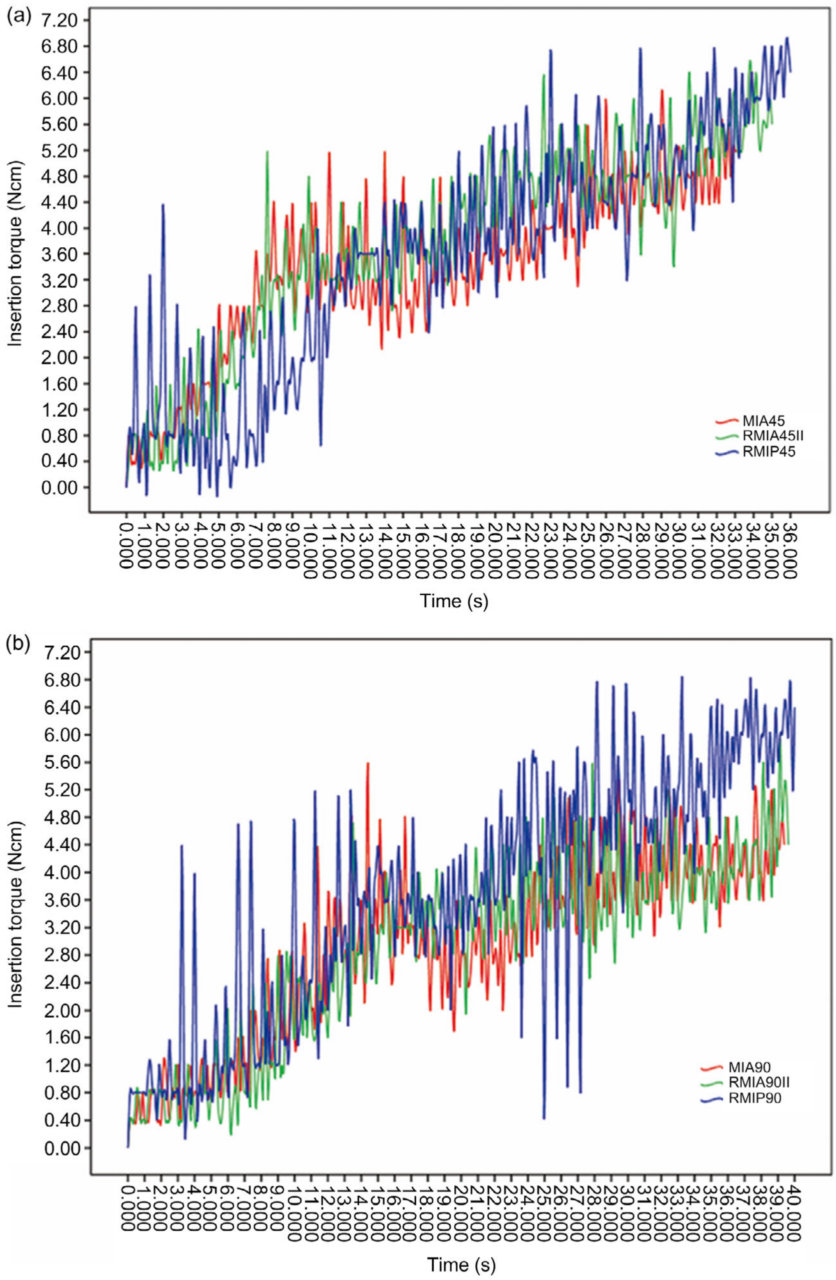

Fig. 5 Representative graphs of insertion torque and insertion time during the insertion process
(a) RMIP45 (blue), MIA45 (red), and RMIA45II (green); (b) RMIP90 (blue), MIA90 (red), and RMIA90II (green) (Note: for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

tip and thread edges. Beyond that, more changes were observed in RMIP, i.e. more worn tip and thin deposits covering the surfaces. This was understandable because clinically used microimplants were loaded more with different orthodontic forces and contacted with patients' bone tissues during their clinical use. Patil et al. (2015) also showed similar results in RMIP and hence support our results.

In order to evaluate the worn degree quantitatively, we measured the residual length of retrieved microimplants. The length of the RMIP was shorter than the new microimplants statistically; however, the difference between them was less than 0.1 mm. It seemed not to have a significant influence on the mechanical behavior of microimplants. Alrbata et al. (2015) compared the mechanical behavior of microimplants with the same thread design but different tip lengths (1.00 mm vs. 1.25 mm), and found that the mean MIT was not significantly different between the two groups but the insertion time was shorter in the 1.25 mm group. Although it is uncertain that wearing of tip and thread edges have a great effect on mechanical behavior of the retrieved microimplants, we can speculate that the mechanical behavior might be changed to some extent with the cumulative effect of the worn tip and thread edges and the subsequent reduction of their penetration and cutting capabilities.

To identify the specific elements on the surface of microimplants, we undertook a surface composition analysis. Besides the main elements, traces of Fe, S, and Ca were found in RMIP, which came from bone, tissue fluids, and blood. The microimplants retrieved from patients in this study were all used for a very long period (at least 8 months); however, no other foreign elements were found compared with previous studies (Eliades et al., 2009; Chung et al., 2014; Patil et al., 2015). Further studies are needed to investigate the correlation between deposition on the surface of microimplants and their work duration. Considering heterogeneous contamination and immunologic response, the allogeneic reuse of microimplants should not be recommended, and more studies are also needed to improve the present recycling process.

4.3 Mechanical behavior

Presently, MIT, insertion time, removal torque, resonance frequency, and pull-out strength can be used to analyze the mechanical properties of microimplants. MIT has been considered as an indicator for the primary stability of microimplants (Motoyoshi et al., 2006; Lim et al., 2008), i.e. the largest value of torque recorded during the rotation process of the microimplant insertion in torsional shear (ASTM, 2013). Insertion time can reflect cutting and penetrating capabilities (Chung et al., 2014; Alrbata et al., 2015). Removal torque value is an indirect measurement of bone-implant contact or clinical osseointegration. Resonance frequency analysis is a non-invasive method that reflects microimplant stability and bone density using vibration and a principle of structural analysis. Because MIT and insertion time are easy for the orthodontist to measure in the clinic and we also measure them in daily clinical practice, we chose these two common parameters and recorded them under clinically simulating conditions. This is also the main reason why we did not choose pull-out strength as a parameter since this cannot be carried out in clinical practice. As for removal torque, the artificial bone block could not have an osseointegration effect between polyurethane and titanium surfaces, and thus it also was not chosen.

The MIT of RMIA in this study was greater than that of the new microimplants. This MIT increase probably resulted from the cumulative effect of the wear-out of tips and thread edges, lowering the cutting and penetration capabilities. The trend of MIT increase in RMIA compared to MIA was consistent with the study by Noorollahian et al. (2015); however, the MIT mean value for the first insertion and the difference between the first insertion and reinsertion in their study were all greater than those in this study. This difference may be caused by the different microimplants and the artificial bones used in the two experiments (Song et al., 2007; Lim et al., 2008). The MIT of RMIP was also larger than RMIA. The difference between RMIA and RMIP could be due mainly to the irregular deposits on the surface of RMIP. The irregular deposits could increase roughness of the RMIP surface, i.e. the friction coefficient, thereby increasing the friction and MIT value. From the two results mentioned above, we can deduce that the MIT increase of RMIP compared to MIA could be caused by not only the cumulative effect of worn tips and thread edges but also the irregular deposits on the surface.

Previous studies showed that a certain level of MIT was necessary for microimplants to achieve primary stability (Motoyoshi et al., 2006, 2007a, 2007b, 2010; Chaddad et al., 2008). Motoyoshi et al. (2006) recommended limiting MIT to the range of 5 to 10 Ncm for a high success rate for 1.6-mm diameter and 8-mm long mini-implants. Considering that MIT is proportional to the length and diameter of the microimplant (Lim et al., 2008), the recommended MIT range could be smaller for the small microimplant tested in this study (1.3-mm diameter) (Alrbata et al., 2015). In this study, the MIT of retrieved microimplants increased to some extent during reinsertion, and the increase was more significant in RMIP than RMIA. As shown in previous studies, excessive insertion torque was thought to be associated with excessive bone compression, micro-damage and subsequent necrosis of the surrounding bone (Ueda et al., 1991; Moon et al., 2008; Wawrzinek et al., 2008; Lee and Baek, 2010; Togni et al., 2011). Therefore, microimplant reuse for immediate relocation can be accepted because of little increase in MIT; however, for postponed relocation, the reuse is not recommended owing to greater increase in MIT and surface compositional changes.

As for the different insertion angles, an increasing trend of MIT was seen in MIA, RMIA, and RMIP inserted at the insertion angle of 45° compared with 90°; however, the difference had no statistical significance. This trend can be interpreted as placement of microimplants in an oblique direction bringing about a longer distance through cortical bone and more cortical bone contact (Wilmes et al., 2008); however, the fact that the trend was not significant may be because the microimplants were very thin and the cortical bone was also not very thick in this study. Therefore, microimplant reuse for immediate relocation at some angles can be acceptable; however, this increasing trend should be kept in mind as a possible influencing factor on MIT.

The insertion time was increased in retrieved microimplants compared with MIA. This could be explained by the fact that the tips and threads of retrieved microimplants are worn out and result in lowered penetration and cutting capacities. When clinicians had to relocate microimplants in a clinical situation, the risk of insertion time increase should be taken into consideration. Meanwhile, sufficient coolant is needed during the reinsertion process to prevent more heat generation and then to prevent possible thermal necrosis of the bone (Yadav et al., 2012).

The insertion time was longer in all groups inserted at 90° than in those corresponding groups inserted at 45°. This difference was understandable because the insertion was stopped once any part of the last thread edge touched the surface of the bone block, and the edge touched the surface earlier in the groups inserted at 45° compared with those inserted perpendicularly.

4.4 Limitation and strength

Although we tried our best to simulate clinical immediate relocation and postponed relocation in this study, the experimental and clinical settings were really not one and the same.

Despite the limitation, this study is the first to compare the two resources of retrieved microimplants (artificial bone vs. patients) on their surface characteristics and mechanical behavior, and the insertion angle has also been considered.

5 Conclusions

Within the limitation of the current study, the null hypothesis was accepted because retrieved microimplants from different sources exhibited different degrees of changes in surface characteristics and mechanical behavior. The ones retrieved from patients showed more wear at the tip and thread edges, thin surface deposits on the surface, and more increased MIT and insertion time.

The recommendations on microimplant reuse are as follows: (1) For the same patient, the reuse of microimplants for immediate relocation at a certain insertion angle can be considered based on specific clinical conditions; however, we will not recommend the reuse for postponed relocation especially in terms of small microimplants. (2) For different individuals, the reuse of microimplants is not recommended in clinical practice.

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Compliance with ethics guidelines

Lu LU and Hyo-Sang PARK declare that they have no conflict of interest.

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study.

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中文概要

题 目：正畸微小种植体临床用后的表面特征与力学性能

目 的：在临床模拟试验条件下，观察正畸微小种植体临床用后的表面特征与力学性能，探讨正畸微小种植体再使用的可行性。

创新点：比较了两种回收来源的正畸微小种植体（临床用后回收和植入人工骨后回收）的表面特征与力学性能，同时还考虑了不同植入角度的影响。

方 法：将符合纳入条件的临床用后正畸微小种植体回收，另将新正畸种植体以不同角度植入临床模拟条件下的人工骨并取出回收，分别比较了不同来源正畸微小种植体的表面特征以及力学性能。使用场发射扫描电镜、立体显微镜以及 X 射线能谱仪评估了正畸微小种植体尖端及螺纹的形态和长度变化，以及表面元素变化等表面特征；并在临床模拟试验条件下测试了最大植入扭矩和植入时间等力学性能（图 1）。

结 论：不同回收来源的正畸微小种植体表现出表面特征以及力学性能的不同变化。临床用后回收的正畸微小种植体尖端及螺纹表现出更多的磨损，其表面附着有一薄层沉积物，最大植入扭矩以及植入时间增大明显。建议正畸微小种植体再使用时，针对同一患者在某些临床条件下可考虑植入后立即取出并以一定角度再植入，但是临床使用过一段时间的正畸种植体尤其是微小种植体不建议再次植入；针对不同患者，临床操作中不建议微小种植体的再次使用。

关键词：正畸微小种植体；表面特征；力学性能；回收分析