Effects of recycling process on the biomechanical characteristics of orthodontic mini-screws

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Effects of recycling process on the biomechanical characteristics of orthodontic mini-screws

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감사의 글

여러모로 부족한 점이 많은 저를 차분하고, 꼼꼼하게 지도해 주신 황충주 교수님께 깊은 존경과 감사의 뜻을 전합니다. 교정의로서, 그리고 인생의 선배로서 많은 가르침을 주신 교수님의 은혜 평생 잊지 않겠습니다.

만날 때마다 따듯하게 반겨주시고 논문에 깊은 관심을 가져주신 유형석 교수님, 부족한 논문을 꼼꼼하게 수정해주신 차정열 교수님, 실험에 대한 준비 및 방향을 일러주시고 충고를 아끼지 않으신 김광만 교수님, 그리고 처음 본 대학원생임에도 따뜻한 미소로 반겨주시고 예리한 지적을 해주신 김진 교수님께도 감사 드립니다.

또한 연세대 대학원에 들어올 수 있게 도와주시고 뵐 때마다 인자한 미소로 악수를 청하시는 박영철 교수님께도 깊은 감사의 뜻을 전하며, 부족한 논문에 관심을 갖고 조언해주신 백형선, 김경호, 이기준, 정주령, 최윤정, 최성환 교수님께도 깊이 감사 드립니다.

그리고 실험 과정 동안 도와주신 여러 의국원 및 실험실 직원 분들께도 감사의 뜻을 전합니다.

마지막으로 박사 들어가는 것은 못 보셨지만, 하늘에서 기뻐하고 계실 아버지와 저를 항상 자랑스럽게 생각해 주시는 우리 가족들에게 감사 드립니다. 특히 부족한 남편을 세상 최고로 생각하고 지지해 주는 아내 안시내와 힘든 아빠를 웃게 만들어 주는 우리 비타민들 서빈, 서훈이에게 사랑과 감사의 마음을 담아 이 박사논문을 바칩니다.

2016 년 6 월 저자 윤 순 동

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Abstract

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The aim of this study was to compare surface properties, mechanical characteristics, and biological responses between recycled and unused orthodontic mini-screws to determine the feasibility of reuse from the biomechanical aspect. We also included both screws with machined surface (MS) and those with etched surface (ES) to further assess the effects of recycling with regard to surface treatments.

To simulate initial use, MS and ES were placed in the maxilla of four beagle dogs and maintained for 4 weeks. Retrieved MS and ES were further divided into three subgroups (A,B,C) according to the assigned recycling procedure: group A, air–water spray only; group B, mechanical cleaning only; and group C, mechanical and chemical cleaning. Unused screws (group D) were used as control. Scanning electron microscopy (SEM), energy-dispersive X-ray spectrometry (EDS) were assessed for all group and insertion time and maximum insertion torque measurements in artificial bone, and biological responses in the form of

Periotest values (PTV), bone–implant contact ratio (BIC), and bone volume ratio (BV) were assessed for group C and D.

The results of this study were as follows.

1. Morphological changes after recycling mainly occurred at the screw tip
2. Retrieved MS could produce similar surface composition with unused screws only by mechanical cleaning, while ES need chemical cleaning as well after mechanical cleaning to produce similar surface composition with unused screws.
3. The success rate of recycled screws to penetrate cortical bone was lower than that of unused screws. However, there was no significant difference between recycled screws that successfully penetrated to the cortical bone and unused screws in IT and MIT (P >0.05).
4. PTV, BIC, and BV according to healing time showed remarkable changes. Especially, the increase of PTV and decrease of BIC and BV after 8 weeks of healing time was statistically significant (P < 0.01).
5. There was no statistically significant difference in PTV and BIC between recycled and unused screws (P >0.05). However, BV of the recycled screw was lower than that of the unused screw and this difference was statistically significant (P < 0.05).

In conclusion, the results of our study suggest that used orthodontic mini-screws can achieve a surface composition similar to that of unused screws when subjected to appropriate

recycling processes, with mechanical and chemical cleaning showing the best effects together. However, screw tip deformation remains a concern, necessitating pre-drilling or an increase in the vertical force for cortical bone penetration. Furthermore, biological responses may differ between recycled and unused screws. Taken together, reuse of recycled orthodontic mini-screws may not be feasible from the biomechanical aspect.

Key words : Orthodontic mini-screw, recycling, surface properties, mechanical characteristic, biological response

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I. Introduction

Preparation for adequate anchorage is important for successful orthodontic treatment. Although various methods are used to reinforce anchorage, orthodontic mini-screws are commonly used of late, considering they can be placed at various site for various purposes, do not depend on patient compliance, can be immediately loaded and are easy to insert and remove.[1]

Nearly all orthodontic mini-screws are sealed and marketed for single use. However, in situations such as initial failure after placement, placement in the path of tooth movement, and the requirement for reuse at different sites for different purposes, retrieved screws can be recycled and reused.[2-4]

Validation of recycling process of medical devices is a current trend. [5,6] The reuse of osteosynthesis plates and screws, which are similar to orthodontic mini-screws has been reported.[7,8] In the field of dentistry, changes in mechanical and surface properties after recycling have been assessed for orthodontic arch wires[9,10] and endodontic NiTi files. [11]

There is growing interest in the investigation of retrieved orthodontic mini-screws with several published studies. Eliades et al [12] observed changes in structural and mechanical properties and surface compositions of retrieved orthodontic screws, while Chung et al [13] observed changes in morphological and mechanical characteristics. Estelita et al [14] and Mattos et al [15] assessed torsional strength changes after recycling, while Noorollahian et al [16] found that recycling does not affect insertion, removal and the fracture torque. In another study, Noorollahian et al [17] observed changes in screw surface compositions of retrieved screws after cleaning with 37% phosphoric acid and 5.25% NaOCL, while El-Wassefy et al [18] reported the effects of different sterilization methods on surface characteristics, ion release, and biological responses.

However, these previous studies generally assessed clinically used screws. Therefore, each screw differed with regard to the placement site, duration of use, applied force, and storage period after retrieval. To minimize the effects of these factors, we placed screws with similar characteristics for 4 weeks before retrieval in beagle dogs in the present study. Furthermore, previous studies mostly assessed screws with a machined surface (MS). However, the use of screws with treated surfaces is gradually increasing, with improved success rates. Therefore, we assessed screws with both machined and etched surfaces (ES) in the present study. [19,20]

Taken together, the aim of the present study was to compare surface properties, mechanical characteristics, and biological responses between recycled and unused orthodontic mini-screws to determine the feasibility of reuse from the biomechanical aspect. We included both screws with MS and those with ES to further assess the effects of recycling with regard to surface treatments.

II. Materials and Methods

1. Experimental animals and materials

Four 12-months-old male beagle dogs, weighing approximately 10 kg were used. Each surgical procedure was approved by the Animal Care and Use Committee of Yonsei Medical Center, Seoul, Korea. All procedures were performed under general anesthesia. Following pre-anesthetic injection of intramuscular medetomidine 10 μg/kg and subcutaneous atropine 0.05 mg/kg, alfaxalone 2 mg/kg was intravenously administered for general anesthesia. Intravenous cefazolin 20 mg/kg and intravenous or subcutaneous ketorolac 0.5 mg/kg were administered for postoperative infection control and analgesia, respectively. After the final experiment, euthanasia was induced by injection of KCl 1-2 mol/kg after the induction of general anesthesia as described above.

Self-drilling orthodontic mini-screws measuring 1.4 mm in diameter, and 6 mm in length were used. Screws with MS (OSSH1406, Osstem implant, Busan, Korea) and ES (OSSH1406HE, Osstem implant, Busan, Korea) were distinguished (Fig 1).

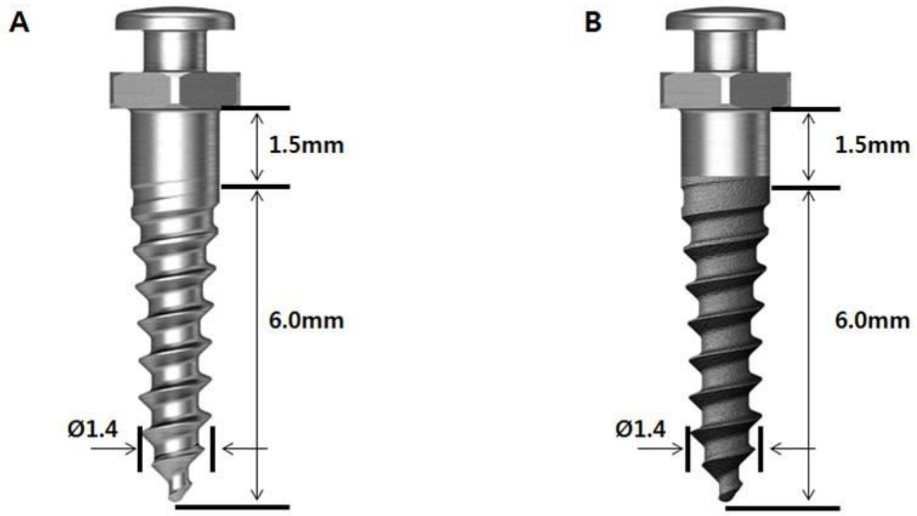

Fig 1. Schematic diagram of orthodontic mini-screws with (A) machined and (B) etched surface.

2. Screw placement

To simulate initial use, all orthodontic mini-screws were placed in the maxilla using an engine driver (ORTHONIA 111-ED-010, Jeil Medical, Seoul, Korea). To minimize the experimental animal number, screws were placed not only buccally but also between the palatal rugae. The right and left sides held the MS and ES groups, respectively. The buccal placement site was between the roots of the second, third and fourth premolars and the first molar (total four) (Fig 2), while the palatal placement site was the deepest area between the rugae, 2 mm from the mid-palatal region at the third and fourth premolars. Fourteen screws (seven MS, seven ES) were placed in each animal (N=56 for four animals). The screws were maintained for 4 weeks with a soft diet before retrieval (Fig 3).

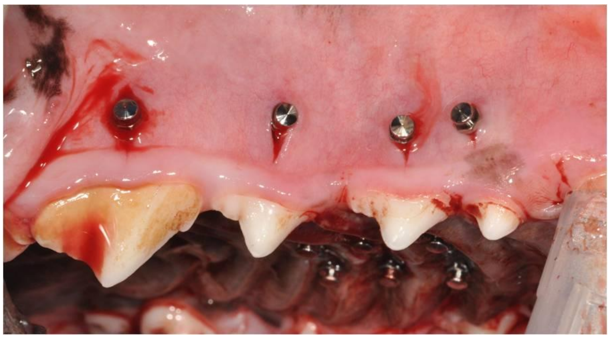

Fig 2. Placement of orthodontic mini-screws in the maxilla

Screws with machined and etched surfaces are placed on the right and left sides, respectively.

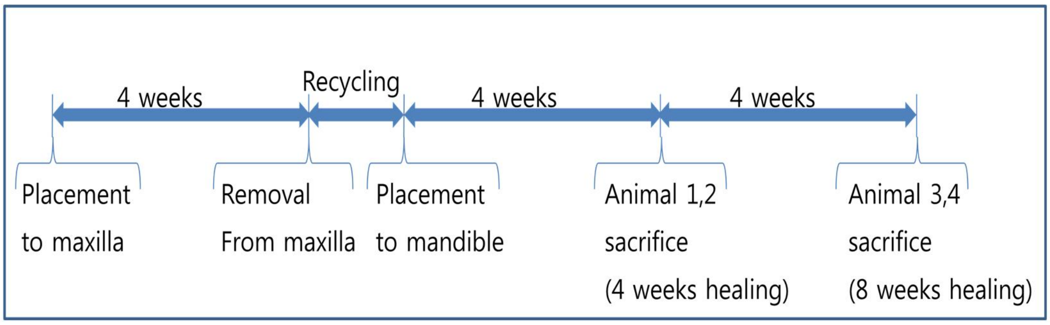

Fig 3. Flowchart of the experiment.

3. Recycling process

All screws were retrieved by a reverse turn of the engine driver 4 weeks after placement. The MS and ES groups were further divided into four subgroups (A, B, C, D) according to the assigned recycling procedure (Table 1). In group A (four MS and four ES), screws were cleaned with an air-water spray, rinsed with distilled water, dried, and sealed in an individual auto-sealing envelope. In group B (four MS and four ES), the surfaces were mechanically cleaned using an air-flow device (Air-flow^{R} handy 2+, EMS, Nyon, Switzerland). The air-flow tip was placed 1 cm from the screw surface, and cleaning was performed for 10-15 sec until all remnants were removed as observed by the naked eye. Then, the screws were rinsed in an ultrasonic bath (SHB-1025, Saehan sonic, Seoul, Korea) with distilled water for 15 min, dried, and sealed in an individual auto-sealing envelope. In group C (20 MS and 20 ES), screws were chemically cleaned after mechanical cleaning. Mechanically cleaned screws were thoroughly dried, completely immersed in 37% phosphoric acid (Dentto-Etch 37, Mediclus Co, Seoul, Korea) for 10 min, irrigated with distilled water and dried, immersed in 6% sodium hypochlorite (RC cleaner, Il-Chung dental Co, Seoul, Korea) for 15 min, rinsed in an ultrasonic bath with distilled water for 15 min, dried, and sealed in an individual auto-sealing envelope (Fig 4). All 56 sealed screws were sterilized at 121℃ and 18 psi for 20 min in an autoclave as manufacturer's guide (STP-103, Hanshin Medical Co, Incheon, Korea). Group D included 40 unused, autoclaved screws (20 MS and 20 ES) as controls.

Table 1. Classification of orthodontic mini-screws based on the recycling method

Group	Cleaning process
A	air–water spray only and distilled water irrigation
B	mechanical cleaning
C	mechanical cleaning + chemical cleaning
D	unused screw

Mechanical cleaning: air–flow (10–15 sec) and ultrasonic irrigation (15 min)

Chemical cleaning: immersion in 37% phosphoric acid (10 min)

and 6% sodium hypochlorite (15 min) and ultrasonic irrigation (15 min)

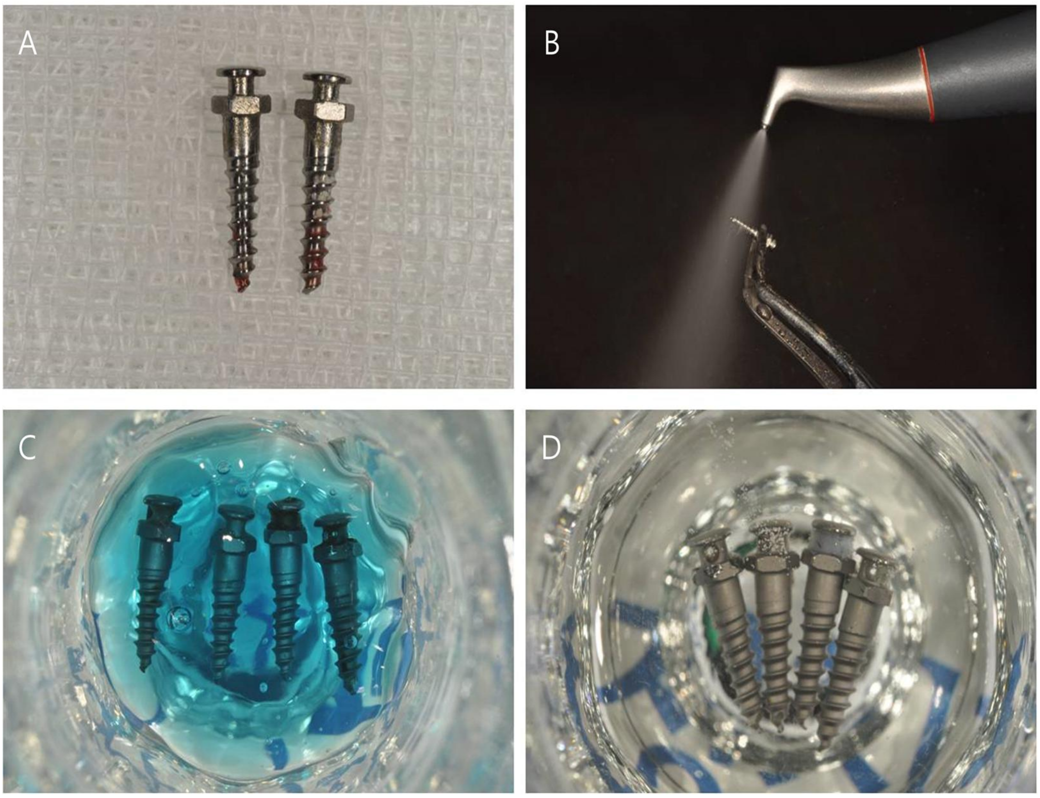

Fig 4. Images of the recycling processes used in the present study:7

A, retrieved screws; **B**, air-flow with glycine powder (mechanical cleaning); **C**, immersion in 37% phosphoric acid (10 min; chemical cleaning); and **D**, immersion in 6% sodium hypochlorite (15 min; chemical cleaning).

4. Surface properties

1) Scanning electron microscopy

To assess changes in surface properties after recycling, we performed field emission scanning electron microscopy (SEM; JSM-7001F, JEOL, Tokyo, Japan) with a 15-kV accelerating voltage and without coating of samples (Fig 5). First, we observed the lateral side of screws, the thread deformation and amount of residual remnants under a magnification of ×80, which was then increased to ×200 and ×500 for detailed observation of remnants.

Then, we observed the amount of screw tip deformation under a magnification of ×80 in the vertical direction. The magnification was then increased to ×200 for the observation of surface remnants.

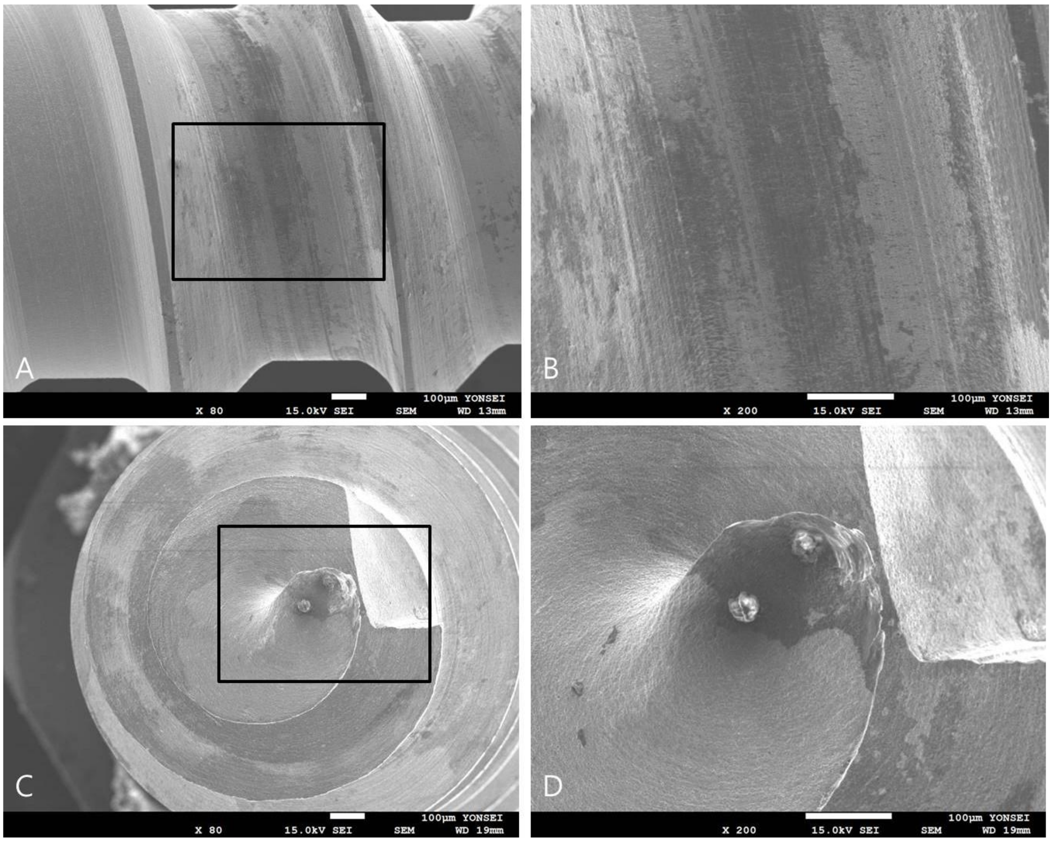

Fig 5. Scanning electron microscopy (SEM) images of an orthodontic mini-screw (etched surface) recycled by air–water spray and distilled water cleaning (group A)

A, Lateral side under ×80 magnification; **B**, lateral side under ×200 magnification (black box in **A**); **C**, screw tip under ×80 magnification; **D**, screw tip under ×200 magnification (black box in **C**)

2) Energy-dispersive X-ray spectroscopy (EDS)

EDS was performed to evaluate the surface elemental composition at the deepest area between threads in the mid-portion of screws. The percentage of each element was analyzed using the EDS system software (AZtecEnergy analysis software, Oxford Instruments PLC, Oxon, United Kingdom).

5. Mechanical characteristics

To compare the mechanical characteristics of recycled screws and unused screws, the insertion time and maximum insertion torque were measured using a driving torque tester (Biomaterials Korea Inc., Seoul, Korea). Five unused and five recycled screws each from the MS and ES groups were inserted for measurements. A 500-g load was added to the 1.14-kg of the torque tester; the total perpendicular force was thus 1640 g. Screws were inserted with a uniform speed of 3 rpm according to the American Society for Testing and Materials (ASTM) F543-02 guidelines. To standardize the insertion conditions, an artificial bone block (Sawbones, Pacific research Laboratories Inc, Vashon Island, WA, USA) with 1-mm-thick cortical bone was used (Table 2), and intervals between adjacent screws were ≥10 mm.

During insertion, the torque was measured every 0.1 sec using a computer program (QuickDataAcq, Data Translation, SDK Developer, London, UK), and changes in values according to the insertion time were plotted on a graph (Fig 6). The insertion time was defined as the time from screw tip perforation of the cortical bone to initiation of medullary bone penetration. The maximum insertion torque was defined as the maximum torque value from the beginning to the end of screw insertion.

Table 2. Mechanical properties of the artificial test block

Type of bone	Density (pcf)	Compressive (MPa)		Tensile (MPa)	
		Strength	Modulus	Strength	Modulus
Cortical bone	50	58	1400	32	2000
Cancellous bone	30	19	520	12	427

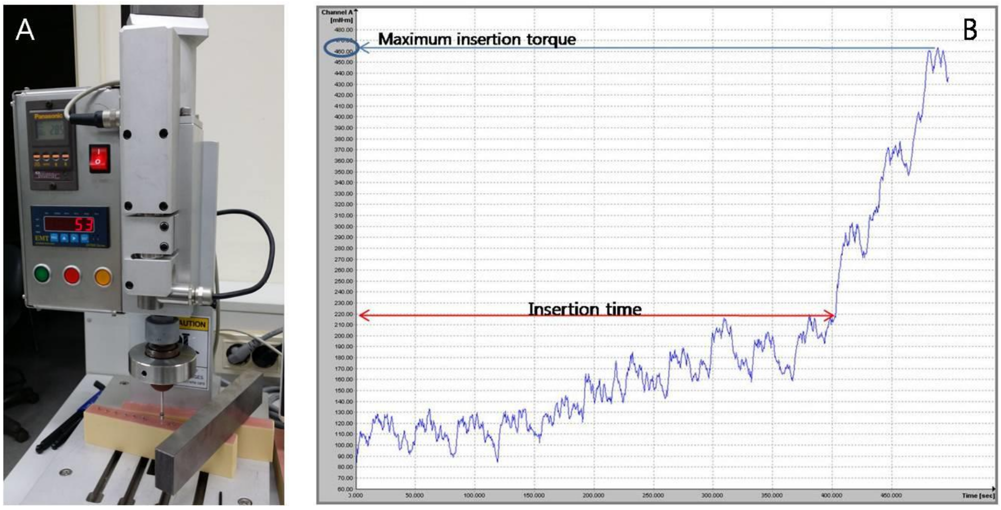

Fig 6. Assessment of mechanical characteristics:

A, photograph of the torque tester used in the present study; **B**, insertion time–insertion torque graph and definition of measurement values (recycled screw with etched surface).

6. Biological responses

1) Screw placement

To compare the effects of recycling on biological responses, four recycled (two MS, two ES) and four unused (two MS, two ES) screws were placed on the same day in the mandible of the four beagle dogs.

Insertion was performed under general anesthesia. The insertion site was infiltrated with lidocaine HCl with 1:100,000 vasoconstrictor. Following incision along the tooth axis, a mucoperiosteal flap was elevated to exposure the alveolar bone thoroughly. Screws were inserted until the threaded portion was sufficiently submerged.

The right and left sides held the ES and MS groups, respectively. Recycled screws were placed between the roots of the second and fourth premolars and unused screws between the roots of the third premolar and first molar.

A soft diet was provided to the animals. Two were sacrificed at 4 weeks after placement and two at 8 weeks. The mechanical stability of each screw was measured three times on the day of insertion and the day of animal sacrifice using Periotest (PTV; periotest value) (Siemens AG, Munich, Germany)

2) Histometric analysis

The mandible was separated and carefully sectioned at the second, third, and fourth premolar and first molar regions to avoid damage to the screw insertion site. Each tissue block was fixed in 10% formalin for 4 weeks, dehydrated using 70-100% ethanol, and embedded in methacrylate-based resin. Polymerized blocks were cut into 100-μm-thick sections according to the longitudinal axis of the screw using an EXAKT macrocutter (Exakt, Apparatebau, Norderstedt, Germany). These sections were ground and polished to a 15-μm thickness using an EXAKT microgrinder. The prepared tissue was stained with hematoxylin–eosin and mounted on a slide.

Each slide was analyzed using light microscopy (BX50; Olympus, Tokyo, Japan) under a ×50 magnification. Histometric measurements were obtained using an image analysis program (Image-Pro Plus®, Media Cybernetics, Silver Spring, MD).

To observe the effects of recycling on the biological response, the bone–implant contact ratio (%BIC; length of bone tissue in direct contact with the screw/total screw surface length from the outermost cortical bone to the third uppermost thread within the bone) and bone volume ratio (%BV; percentage bone area/total area between the imaginary line connecting the top of the thread and the screw surface from the outermost cortical bone to the third uppermost thread within the bone) were measured.

7. Statistical analysis

All statistical analyses were performed using SPSS 20.0 software (SPSS, Chicago, IL, USA). Two-way ANOVA was used for insertion time and maximum insertion torque measurements, and linear mixed model analysis was used for Periotest value (PTV), BIC, and BV assessments. A P-value of $<.05$ was considered statistically significant.

III. Results

1. Surface properties

1) Scanning electron microscopy

No morphological changes such as torsion or thread deformation were visible to the naked eye in any screw.

SEM observation of lateral sides showed that remnants were remarkably decreased by each recycling process (Fig 7). All screws (MS and ES) with air–water spray cleaning (group A) showed remnants as a black stain. These stains were remarkably decreased in mechanically cleaned screws (group B), with a greater decrease for MS than for ES. With regard to mechanically and chemically cleaned screws (group C), few or no stains were observed in the MS and ES groups, with surface conditions similar to those of unused screws.

SEM observation of screws tips showed various degrees of damage such as blunting or deformation in all recycled screws, whereas a sharp tip was observed in group D (Fig 8). Surface remnants appearing as stains showed trends similar to those observed for the lateral sides.

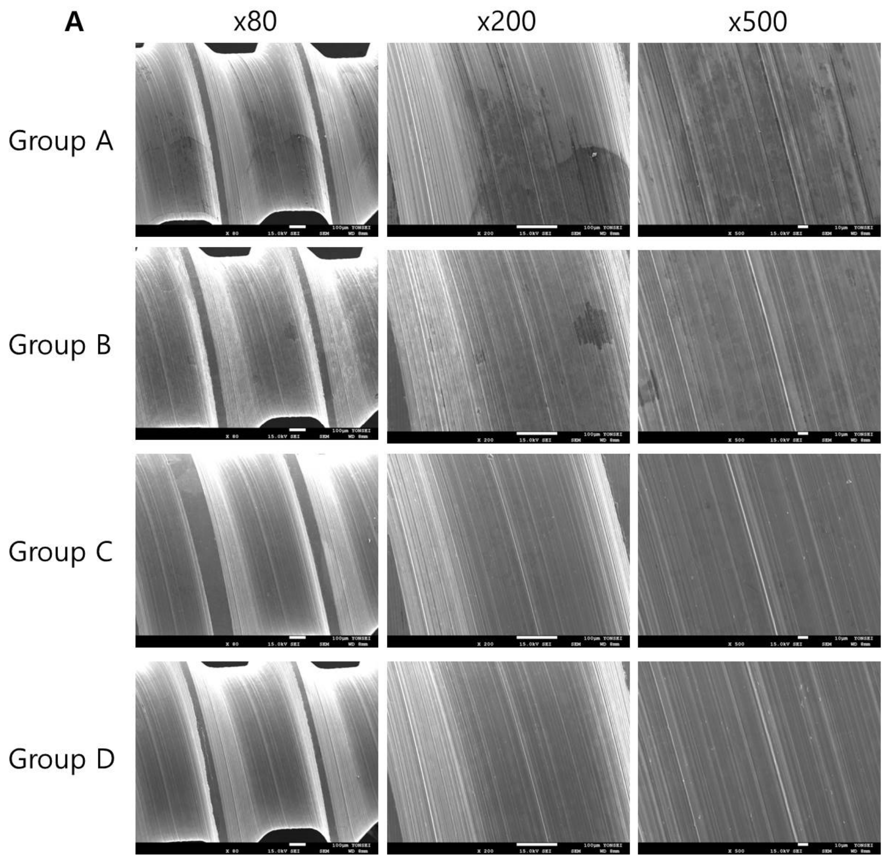

Fig 7. Scanning electron microscopy (SEM) images of the lateral side of orthodontic mini-screws with a **(A)** machined surface and an **(B)** etched surface (×80, ×200 and ×500) :

Group A: air–water spray only and distilled water irrigation

Group B: mechanical cleaning

Group C: mechanical cleaning + chemical cleaning

Group D: unused screw (control).

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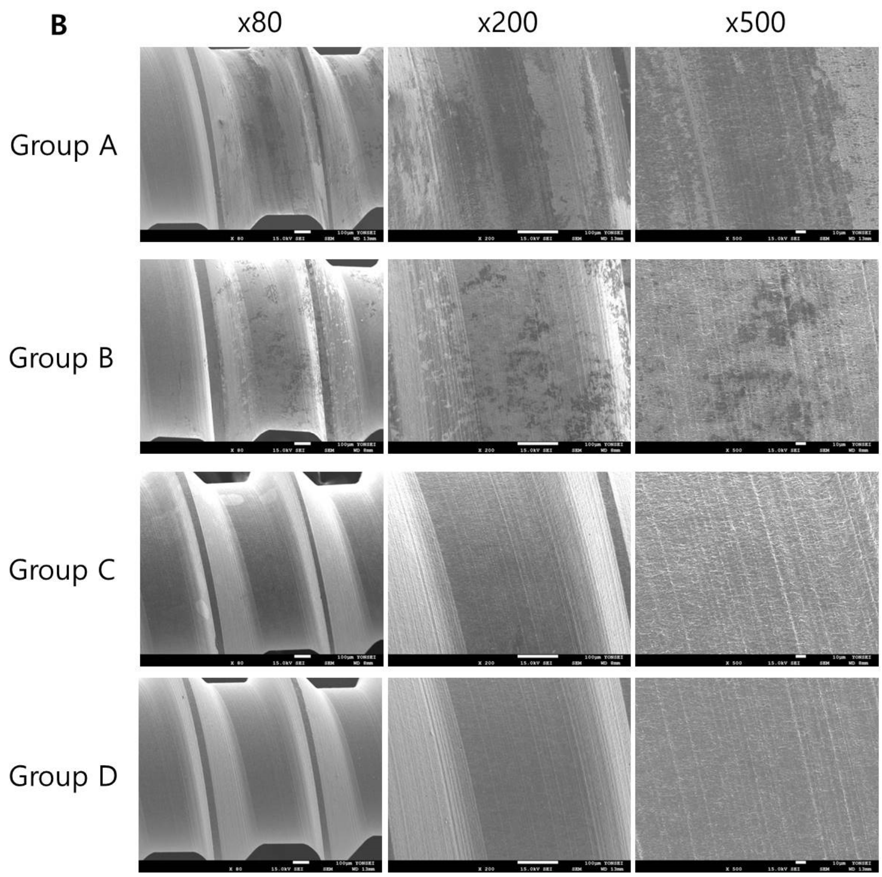

Fig 7. Scanning electron microscopy (SEM) images of the lateral side of orthodontic mini-screws with a **(A)** machined surface and an **(B)** etched surface (×80, ×200 and ×500) :

Group A: air–water spray only and distilled water irrigation

Group B: mechanical cleaning

Group C: mechanical cleaning + chemical cleaning

Group D: unused screw (control).

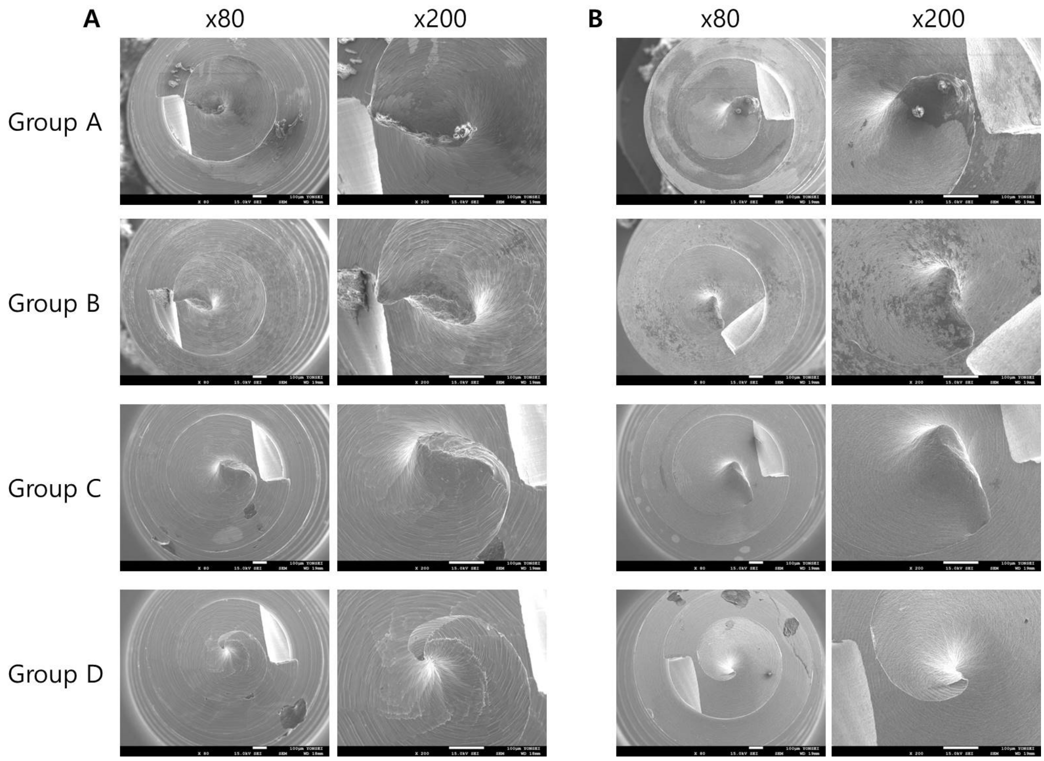

Fig 8. Scanning electron microscopy (SEM) images of the tips of orthodontic mini-screws with a **(A)** machined surface and an **(B)** etched surface (×80, ×200) :

Group A: air–water spray only and distilled water irrigation

Group B: mechanical cleaning

Group C: mechanical cleaning + chemical cleaning

Group D: unused screw (control).

2) Energy-dispersive X-ray spectroscopy (EDS)

A high number of organic [carbon (C), oxygen (O)] and inorganic elements [calcium (Ca), phosphorous (P)] were detected in both MS and ES groups of screws cleaned with air–water spraying. These elements were remarkably decreased in mechanically cleaned screws with MS and ES. Elements such as O, Ca, and P were not detected in the mechanically cleaned screws with MS, and the amount of C was similar between these screws and unused screws. Mechanically and chemically cleaned screws showed a surface composition similar to that of unused screws, regardless of MS or ES (Table 3).

Table 3. Energy-dispersive X-ray spectroscopy (EDS) analysis of the chemical composition of orthodontic mini-screw surfaces

Element	Machined surface (wt %)				Etched surface (wt %)			
	Group A	Group B	Group C	Group D	Group A	Group B	Group C	Group D
C	5.79	2.54	2.66	2.42	6.57	4.53	2.73	2.45
Al	5.15	5.58	5.61	5.58	3.64	4.98	6.24	5.67
Ti	77.83	88.15	88.28	88.39	60.68	77.42	87.13	88.05
V	3.21	3.73	3.45	3.61	2.81	3.45	3.90	3.83
O	6.73	0.00	0.00	0.00	21.94	8.23	0.00	0.00
Na	0.90	0.00	0.00	0.00	0.25	0.21	0.00	0.00
P	0.15	0.00	0.00	0.00	1.51	0.45	0.00	0.00
Ca	0.23	0.00	0.00	0.00	2.59	0.73	0.00	0.00

Group A: air–water spray only and distilled water irrigation

Group B: mechanical cleaning

Group C: mechanical cleaning + chemical cleaning

Group D: unused screw (control)

Mechanical cleaning: air–flow (10–15 s) and ultrasonic irrigation (15 min)

Chemical cleaning: immersion in 37% phosphoric acid (10 min) and 6% sodium hypochlorite (15 min) and ultrasonic irrigation (15 min).

2. Mechanical characteristics

All 10 (five MS and five ES) unused screws were successfully inserted in artificial bone, whereas two recycled screws with MS and two with ES failed to penetrate the cortical bone (40% failure rate). The successfully inserted recycled screws showed similar insertion time and maximum insertion torque values (Table 4).

Table 4. Mean and standard deviation values for the mechanical characteristics of unused and recycled orthodontic mini-screws with etched or machined surfaces

		N	IT (s)	MIT (mN.m)
Machined surface	Unused	5	442 ± 8.3	454 ± 15.1
	Recycled	3	450 ± 43.5	473 ± 30.5
Etched surface	Unused	5	470 ± 57.9	452 ± 20.4
	Recycled	3	426 ± 15.2	460 ± 30.0
Sig (Machined vs. Etched)			0.90	0.52
Sig (Unused vs. Recycled)			0.39	0.26

IT, insertion time; **MIT**, maximum insertion torque

Sig, statistical significance (*P* < .05)

3. Biological responses

1) Periotest value (PTV)

No significant differences were observed at insertion or sacrifice with regard to the surface treatment, i.e., MS and ES, and recycling status, i.e., recycled and unused. However, the mechanical stability showed differences according to the healing time. Compared with the mobility at insertion, the mobility at 4 weeks and 8 weeks after placement showed an increasing tendency, with the increase at 8 weeks showing statistical significance (Table 5).

2) Histometric analysis

BIC (%) and BV (%) were higher for the ES groups than for the MS groups, although the differences were not significant. BV of unused screws was significantly higher than that of recycled screws, whereas BIC showed no significant differences. Both BIC and BV were significantly higher at 4 weeks than at 8 weeks (Fig 9)(Table 5).

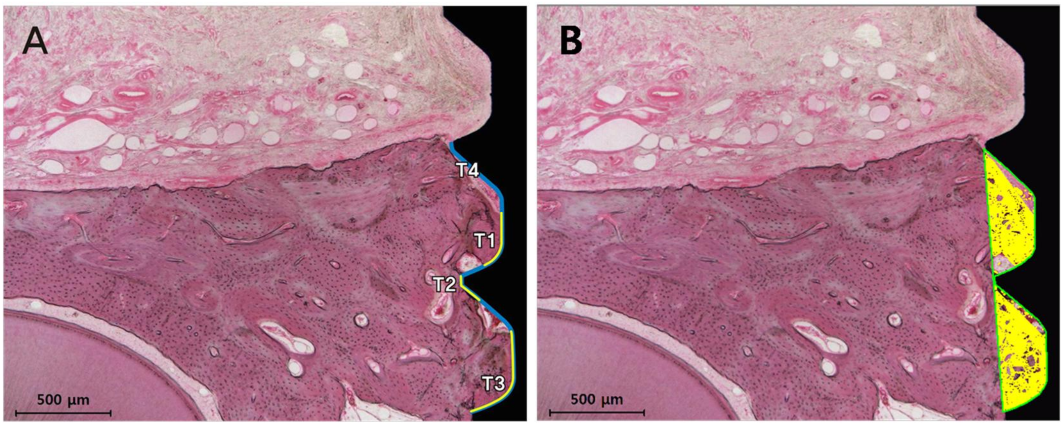

Fig 9. Measurements of **(A)** Bone–implant contact ratio (%BIC), T1 + T2 + T3 (yellow line) / T4 (blue line) and **(B)** Bone volume ratio (%BV), yellow area / area within the green line

Table 5. Mean and standard deviation values for the PTV, BIC, and BV according to the healing time, surface properties, and recycling status of orthodontic mini-screws

		N	Periotest values (PTV)		BIC (%)	BV (%)
			Insertion	Removal		
Healing period	4 weeks	16	−1.3 ± 1.8	−1.1 ± 1.5	80 ± 19	88 ± 10
	8 weeks	16	−1.8 ± 1.4	1.1 ± 2.6**	67 ± 14 **	83 ± 7**
Surface properties	MS	16	−1.3 ± 1.6	0.2 ± 2.1	73 ± 16	85 ± 7
	ES	16	−1.8 ± 1.6	−0.2 ± 2.7	75 ± 19	86 ± 11
Recycling status	Unused	16	−1.4 ± 1.7	0.4 ± 1.9	74 ± 19	87 ± 9
	Recycled	16	−1.7 ± 1.6	−0.4 ± 2.7	74 ± 16	84 ± 9*

BIC, bone–implant contact ratio; **BV**, bone volume ratio

MS, machined surface; **ES**, etched surface

*P < .05, **P < .01

IV. Discussion

In the present study, we compared surface properties, mechanical characteristics, and biological responses between recycled and unused orthodontic mini-screws with MS and ES to determine the feasibility of reuse from the biomechanical aspect. In principle, orthodontic mini-screws are intended for single use. However, with the recent increase in social concerns about recycling, several studies have evaluated the use of recycled orthodontic mini-screws.

Retrieved screws should not carry an increased risk of infection and must have mechanical characteristics and biological responses similar to those of unused screws.

To eliminate the risk of infection, screw surface remnants must be thoroughly removed. The recycling process of titanium screws can be divided into cleaning and sterilization procedures.[21] Cleaning removes large remnants visible to the naked eye, such as blood, bone particles, and soft tissue, and small remnants such as the biofilm. Cleaning can be mechanical and/or chemical. Mechanical cleaning includes brushing and scrubbing, although these methods can cause severe damage to screw surfaces.[22] Therefore, we assessed screws subjected to air-flow cleaning with glycine powder in the present study.[23-25] Air-flow cleaning with glycine powder causes minimal damage to screw surfaces and inhibits bacterial recolonization for a short duration (24 h). Consequently, it is considered effective in the treatment of peri-implantitis. Following air-flow cleaning, screws are rinsed in an ultrasonic bath with distilled water for 15 min to disrupt the residual debris.[21]

Chemical cleaning removes the slight amounts of organic and inorganic remnants after mechanical cleaning. Park et al[21] studied the effects of sequential cleaning an enzymatic solution (trypsin digestion), 2% microsoap, acetone, isopropanol, and ethanol on titanium discs and concluded that recycled titanium discs can be restored to an unused condition with two sessions of this cleaning cycle. However, this cycle is difficult for clinical use. In the present study, we used 37% phosphoric acid and 6% NaOCl, which are commonly used in clinics, cheap, and easy to manipulate. The former is commonly used to etch enamel surfaces and is effective in the removal of inorganic materials from screw surfaces.[17, 26] The latter is commonly used in root canal therapy and is effective in the removal of organic materials.[17, 27] Accordingly, both chemicals together remove organic and inorganic materials without damaging the titanium surface at room temperature and are considered effective for titanium screw recycling.[17]

The last step of recycling is sterilization, wherein reproduction of microorganisms such as bacteria, spores, and fungi is eliminated or prevented[21] and probable protein remnants are denatured to decrease the risk of allergenicity.[17] Autoclaving, gamma irradiation, oxygen plasma treatment, and ultraviolet radiation are used methods. We used autoclaving, the most common method in dental clinics, in the present study.

SEM observations showed that MS, but not ES, can be effectively cleaned by mechanical procedures alone. This suggests that glycine powder cannot reach the ES surface effectively because of surface irregularities. Sahrmann et al[24] reported that the cleaning efficacy for titanium implant surfaces differs according to the angulation of the air-flow device; a 90° angulation was considered most effective. However, ES is irregular, and it is impossible to apply the air-flow device at 90° to the entire surface. Therefore, more surface remnants are left in ES than in MS. In the present study, chemically cleaned screws with MS and ES showed surface properties similar to those of unused screws (group D).

We clarified our SEM findings with EDS analysis. Orthodontic mini-screws are primarily fabricated from Ti6Al4V alloy. Therefore, other elements in the titanium alloy, except titanium (Ti), vanadium (V), and aluminum (Al), indicate screw surface contamination. C and O are the base elements of organic molecules and are derived from contact with biological fluids, whereas P and Ca are the base elements of inorganic molecules and are derived from screw surface contact with blood or selective osseointegration islets.[12, 13] The most noticeable difference in the surface composition between MS and ES was observed for mechanically cleaned screws. While screws with MS showed a surface composition similar to that of unused screws, those with ES showed excessive remnants, although they were lesser compared to those in air–water spray-cleaned screws. Mechanically and chemically cleaned screws also showed a surface composition similar to that of unused screws, regardless of MS or ES. On every screw surface, including control group screws, C was detected in addition to Ti, Al, and V. These carbon-based contaminants probably originated from screw surface contact with air during autoclaving or laboratory procedures. Park et al[21] reported that autoclaving resulted in a greater amount of carbon-rich matter on the surface of titanium discs compared with other sterilization methods and increased the hydrophobicity and contact angle.

All mechanically and chemically cleaned screws showed no torsion, thread deformation, or fracture. The most remarkable morphological changes were detected at the screw tip area. Almost all recently developed orthodontic mini-screws are the self-drilling type. A sharp screw tip is therefore necessary for efficient cortical bone penetration.[13, 28] In the present study, while all unused screws were successfully inserted in artificial bone, two recycled screws with MS and two with ES failed to penetrate the cortical bone. Considering the vertical force, rotation speed, and bone quality were the same, insertion failure indicated severe deformation or blunting of the screw tip.

Successfully inserted recycled screws and unused screws showed similar maximum insertion torque values, which suggests that the overall screw morphology except that at the screw tip remained unchanged after recycling. Also, insertion time showed no differences between recycled and unused screws. If the vertical force was increased, the recycled screws with insertion failure could have penetrated the cortical bone and the insertion time could have decreased.[13] However, excessive vertical force or pre-drilling can result in microcracks or thermal necrosis of cortical bone and, consequently, screw failure; therefore, vertical force should be carefully increased.[29, 30]

We also compared biological responses in vivo with regard to the healing time (4 or 8 weeks), surface treatment (MS or ES), and recycling status (recycled or unused).

Periotest is the most common method to measure the mechanical stability of prosthodontic implants and orthodontic mini-screws.[31, 32] Although its sensitivity varies with the measuring angle and distance from the screw head to probe, it is easy to use and noninvasive.

Histometric measurements for testing the stability of implants or orthodontic mini-screws commonly include BIC and BV, although the definitions vary among researchers.[20, 33-35] The mechanical stability of orthodontic mini-screws is primarily affected by mechanical interlocking in the cortical bone area. Accordingly, we regulated the range of BIC measurements from the outermost cortical bone to the third uppermost thread within the bone. BV was also measured from the total area between the imaginary line connecting the top of the thread and the screw surface from the outermost cortical bone to the third uppermost thread within the bone. This was done to limit the measurement area to as close to the screw surface as possible.

PTV increased according to the healing time in the present study. Both BIC and BV were significantly higher at 4 weeks than at 8 weeks. The increase in PTV and decrease in BIC and BV over time can be explained by the bone remodeling process.[36, 37] From 1 to 8 weeks, when inflammatory reactions and bone resorption are dominant, BIC and BV decrease with a decrease in the bone density, resulting in screw mobility and increased PTV.

BIC and BV were higher for the ES groups than for the MS groups, although the differences were not significant. This result was similar to that of previous studies.[20, 38, 39]

BV of unused screws was significantly higher than that of recycled screws, whereas BIC showed no significant differences. This finding suggest that biological responses show some difference between recycled and unused screws, regardless of the recycling procedure.

In conclusion, the results of our study suggest that used orthodontic mini-screws can achieve a surface composition similar to that of unused screws when subjected to appropriate recycling processes, with mechanical and chemical cleaning showing the best effects together. However, screw tip deformation remains a concern, necessitating pre-drilling or an increase in the vertical force for cortical bone penetration. Furthermore, biological responses may differ between recycled and unused screws. Taken together, reuse of recycled orthodontic mini-screws may not be feasible from the biomechanical aspect.

Further studies with a larger sample size are required to decrease statistical error. In addition, in vivo studies with longer healing periods may show different results.

V. Conclusions

In the present study, we compared surface properties, mechanical characteristics, and biological responses between recycled and unused orthodontic mini-screws to determine the feasibility of reuse from the biomechanical aspect. We included screws with both MS and ES to further assess the effects of recycling with regard to surface treatments.

The results were as follows:

1. Morphological changes after recycling mainly occurred at the screw tip
2. Retrieved MS could produce similar surface composition with unused screws only by mechanical cleaning, while ES need chemical cleaning as well after mechanical cleaning to produce similar surface composition with unused screws.
3. The success rate of recycled screws to penetrate cortical bone was lower than that of unused screws. However, there was no significant difference between recycled screws that successfully penetrated to the cortical bone and unused screws in IT and MIT (P >0.05).
4. PTV, BIC, and BV according to healing time showed remarkable changes. Especially, the increase of PTV and decrease of BIC and BV after 8 weeks of healing time was statistically significant ($P < 0.01$).
5. There was no statistically significant difference in PTV and BIC between recycled and unused screws (P >0.05). However, BV of the recycled screw was

lower than that of the unused screw and this difference was statistically significant ($P < 0.05$).

In conclusion, the results of our study suggest that used orthodontic mini-screws can achieve a surface composition similar to that of unused screws when subjected to appropriate recycling processes, with mechanical and chemical cleaning showing the best effects together. However, screw tip deformation remains a concern, necessitating pre-drilling or an increase in the vertical force for cortical bone penetration. Furthermore, biological responses may differ between recycled and unused screws. Taken together, reuse of recycled orthodontic mini-screws may not be feasible from the biomechanical aspect.

References

1. Park HS , Kwon TG. Sliding mechanics with microscrew implant anchorage. Angle Orthod. 2004;74:703-10

2. Chung KR , Choo HR , Kim SH , Ngan P. Timely relocation of mini-implants for uninterrupted full-arch distalization. Am J Orthod Dentofacial Orthop. 2010;138:839-49

3. Baek SH , Lim BM , Kyung SH , Lim JK , Kim YH. Success rate and risk factors associated with mini-implants reinstalled in the maxxilla. Angle Orthod. 2008;78:895-901

4. Lee JH, Choo HR, Kim SH, Chung KR, Giannuzzi LA, Ngan P. Replacing a failed mini-implant with a miniplate to prevent interruption during orthodontic treatment. Am J Orthod Dentofacial Orthop. 2011;139:849-57

5. Hailey D, Jacobs PD, Ries NM, Polisena J. Reuse of single use medical devices in Canada: Clinical and economic outcomes, legal and ethical issues, and current hospital practice. Int J of technology in health care. 2008;24:430-6

6. Popp W, Rasslan O, Unahalekhaka A, Brenner P, Fischnaller E, Fathy M, Goldman C, Gillespie E. What is the use? An international look at reuse of single-use medical devices. Int J of hygiene and environmental health. 2010;213:302-7

7. Danesi V, Cristofolini L, Stea S, Traina F, Beraudi A, Harman M, Viceconti M. Re-use of explanted osteosynthesis devices: A reliable and inexpensive reprocessing protocol. Injury, Int J care injured. 2011;42:1101-6

8. Magetsari R, van der Houwen EB, Bakker MT, van der Mei HC, Verkerke GJ, Rakhorst G, Hilmy CR, van Horn JR, Busscher HJ. Biomechanical and surface physico-chemical analyses

of used osteosynthesis plates and screws-Potential for reuse in developing countries? J Biomed Mater Res Part B: Appl Biomater. 2006;79B:236-44

9. MJ Mayhew, RP Kusy. Effects of sterilization on the mechanical properties and the surface topography of nickel-titanium arch wires. Am J Orthod Dentofaical Orthop. 1988;93:232-6

10. Lee SH, Chang YI. Effects of recycling on the mechanical properties and the surface topography of nickel-titanium alloy wires. Am J Orthod Dentofacial Orthop. 2001;120:654-63

11. Spagnuolo G, Ametrano G, Anto VD, Rengo C, Simeone M, Riccitiello F, Amato M. Effect of autoclaving on the surfaces of TiN-coated and conventional nickel-titanium rotary instruments. Int endodontic J. 2012; 45:1148-55

12. Eliades T, Zinelis S, Papadopoulos MA, Eliades G. Characterization of retrieved orthodontic miniscrew implants. Am J Orthod Dentofacial Orthop. 2009;135:10.e1-10.e7

13. Chung CJ, Jung KY, Choi YJ, Kim KH. Biomechanical characteristics and reinsertion guidelines for retrieved orthodontic miniscrews. Angle Orthod. 2014;84(5):878-84

14. Estelita S, Janson G, Chiqueto K, Ferreira ES. Effect of recycling protocol on mechanical strength of used mini-implants. Int J of Dentistry. 2014;2014:1-5

15. Mattos CT, Ruellas AC, Sant'Anna EF. Effect of autoclaving on the fracture torque of mini-implants used for orthodontic anchorage. J of Orthodontics. 2011;38:15-20

16. Noorollahian S, Alavi S, Rafiei E. The effect of multiple processing and re-use on orthodontic miniscrew torque values. Dent Res J. 2015;12: 243-7

17. Noorollahian S, Alavi S, Monirifard M. A processing method for orthodontic mini-screws reuse. Dent Res J. 2015;9:447-51

18. El-Wassefy N, El-Fallal A, Taha M. Effect of different sterilization modes on the surface morphology, ion release, and bone reaction of retrieved micro-implants. Angle Orthod. 2015;85: 39-47

19. Choi SH, Cha JY, Joo UH, Hwang CJ. Surface changes of anodic oxidized orthodontic titanium miniscrew. Angle Orthod. 2012;82:522-8

20. Cho YC, Cha JY, Hwang CJ, Park YC, Jung HS, Yu HS. Biologic stability of plasma ion-implanted miniscrews. Korean J Orthod. 2013;43:120-6

21. Park JH, Olivares-Navarrete R, Baier RE, Meyer AE, Tannenbaum R, Boyan BD, Schwartz Z. Effect of cleaning and sterilization on titanium implant surface properties and cellular response. Acta Biomaterialia. 2012;8:1966-75

22. Speelman JA, Collaert B, Klinge B. Evaluation of different methods to clean titanium abutments. A scanning electron microscopic study. Clin Oral Impl Res. 1992;3:120-7

23. Cochis A, Fini M, Carrassi A, Migliario M, Visai L, Rimondini L. Effect of air polishing with glycine power on titanium abutment surfaces. Clin Oral Impl Res. 2013;24:904-9

24. Sahrmann P, Ronay V, Sener B, Jung RE, T Attin, PR Schmidlin. Cleaning potential of glycine air-flow application in an in vitro peri-implantitis model. Clin Oral Impl Res. 2012;24:666-70

25. Chairay JP, Boulekbache H, Jean A, Soyer A, Bouchard P. Scanning electron microscopic evaluation of the effects of an air-abrasive system on dental implants: a comparative in vitro

study between machined and plasma-sprayed titanium surfaces. J Periodontol. 1997;68:1215-22

26. Kamburis JJ, Barker TH, Barfield RD, Eleazer PD. Removal of organic debris from bovine dentin shavings. J Endod Sep. 2003;29: 559-61

27. Muhammad SZ, Naseer A. The effects of acid etching time on surface mechanical properties of dental hard tissues. Dent Mater J. 2015;34: 315-320

28. Yun SD, Lim SH. Effect of cutting flute length and shape on insertion and removal torque of orthodontic mini-implants. Korean J Orthod. 2009;39: 95-104

29. Shank SB, Beck FM, D'Atri AM, Huja SS. Bone damage associated with orthodontic placement of miniscrew implants in an animal model. Am J Orthod Dentofacial Orthop. 2012;141:412-8

30. Yadav S, Upadhyay M, Liu S, Roberts E, Neace WP, Nanda R. Microdamage of the cortical bone during mini-implant insertion with self-drilling and self-tapping technique: a randomized controlled trial. Am J Orthod Dentofacial Orthop. 2012;141:538-46

31. Kim ST, Lee JS, Hwang JW, Kim MS, Choi SH, Jung UW. Reosseointegration of mechanically disintegrated implants in dogs: mechanical and histometric analyses. Clin Oral Impl Res. 2013;0:1-6

32. Emeka N, Michael H, Konstnaze W, Martin RT, Friedrich WN, Klaus E. Implant stability and histomorphometry: a correlation study in human cadavers using stepped cylinder implants. Clin Oral Impl Res. 2003;14: 601-9

33. Jung UW, Kim ST, Kim YH, Cha JK, Lee IS, Choi SH. Osseointegration of dental implants installed without mechanical engagement: a histometric analysis in dogs. Clin Oral Impl Res. 2012;23: 1297-1301

34. Eom TG, Jeon GR, Jeong CM, Kim YG, Kim SK, Cho IH, Cho YS, Oh JS. Experimental study of bone response to hydroxyapatite coating implants: bone-implant contact and removal torque test. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;114: 411-8

35. Youn JW, Cha JY, Yu HS, Hwang CJ. Biologic evaluation of a hollow-type miniscrew implant: An experimental study in beagles. Am J Orthod Dentofacial Orthop. 2014;145: 626-37

36. Cha JY, Lim JK, Song JW, Sato D, Kenmotsu M, Inue T, Park YC. Influence of the length of the loading period after placement of orthodontic mini-implants on changes in bone histomorphology: microcomputed tomographic and histologic analysis. Int J Oral Maxillofac Implants. 2009;24:842-849

37. Wei G, Hu Y, Zheng L, Huo J, Tang T, Deng F. Bone remodeling at microscrew interface near extraction site in the beagle dog mandible-histologic and immunohistochemical analysis. J Appl Oral Sci. 2013;21:443-51

38. Oh EJ, Nquyen TD, Lee SY, Jeon YM, Bae TS, Kim JG. Enhanced compatibility and initial stability of Ti6Al4V alloy orthodontic miniscrews subjected to anodization, cyclic precalcification, and heat treatment. Korean J Orthod. 2014 Sep;44:246-53

39. Chang CS, Lee TM, Chang CH, Liu JK. The effect of microrough surface treatment on miniscrews used as orthodontic anchors. Clin Oral Implants Res. 2009 Oct;20:1178-84

국 문 요 약

Recycling process 방법에 따른 교정용 미니스크류의 생역학적 특성

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본 연구에서는 recycled screw 와 unused screw 의 표면특성, 기계적 특성, 생물학적 반응을 비교하여 교정용 미니스크류의 재사용이 생역학적으로 합당한지를 알아보았다. 또한 표면처리 유무에 따른 recycling 의 효과를 추가로 알아보기 위해 machined surface screw (MS)와 etched surface screw (ES)를 비교하여 관찰하였다.

처음 사용하는 것을 재현하기 위해 MS 와 ES 를 beagle dog 의 상악에 식립 후 4 주간 유지하였다. 사용 후 제거한 스크류들은 recycling 방법에 따라 3 군으로 분류하였다 (A, B, C). A 군은 air-water spray 만 시행하였고, B 군은 기계적 세척까지만 시행하였으며, C 군은 기계적 세척 후 화학적 세척까지 시행하였다. Unused screw 들은 (D 군) 대조군으로 이용하였다.

Recycling 에 따른 표면 특성의 변화를 관찰하기 위해 모든 군을 대상으로 field emission scanning electron microscopy (SEM) 관찰과 energy-dispersive X-

ray spectroscopy (EDS) 분석을 시행하였다. C 군과 D 군을 대상으로 기계적 특성 차이를 비교하기 위해 insertion time 및 maximum insertion torque 를 측정하였으며, 생물학적 반응의 차이를 비교하기 위해, beagle dog 4 마리의 하악에 각각 4 개의 recycled screw (MS 두 개, ES 두 개)와 4 개의 unused screw (MS 두 개, ES 두 개)를 식립하였다. 이 중 두 마리는 식립 4 주 후 희생하였으며, 나머지 두 마리는 8 주 후 희생하였다. 각 스크류의 안정성 평가를 위해 식립 당일과 희생 일에 periotest (PTV; periotest value)를 시행하였다. 또한 생물학적 반응의 차이를 관찰하기 위해 bone-implant contact ratio (%BIC)와 bone volume ratio (%BV)를 측정하였다. 그 결과 다음과 같은 결론을 보였다.

1. Recycling 에 따른 교정용 미니스크류의 외형 변화는 주로 tip 부위에서 발생하였다.
2. Retrieved MS 는 기계적 세척만으로도 unused screw 와 유사한 표면 조성을 얻을 수 있는 반면, retrieved ES 는 기계적 세척 후 화학적 세척까지 시행한 후에야 unused screw 와 비슷한 표면 조성을 얻을 수 있었다.
3. Recycled screw 들은 (60%) unused screw 들에 (100%) 비해 피질골 통과 성공률이 낮았다. 하지만 피질골 통과에 성공한 recycled screws 와 unused screws 간에는 IT 및 MIT 에서 통계적으로 유의할만한 차이를 보이지 않았다 (P >0.05).

4. 모든 군에서 치유기간에 따라 PTV, BIC, BV 모두 현저한 변화를 보였다. 특히 8 주 치유기간 후 PTV 의 증가와 BIC, BV 의 감소는 통계적으로 유의할만한 수준이었다 (P <0.01).
5. Recycled screw 는 unused screw 와 비교하여 PTV, BIC 에서는 통계적으로 유의할만한 차이를 보이지 않았다 (P >0.05). 하지만 recycled screw 의 BV 값은 unused screw 에 낮은 값을 보였으며 그 차이는 통계적으로 유의할만한 수준이었다 (P <0.05).

결론적으로, 한번 사용한 교정용 미니-스크류는 적절한 처리과정을 거치면 unused screw 와 비슷한 수준의 표면 조성을 얻을 수는 있다. 하지만 거의 모든 recycled screw 에서 tip 부위의 손상이 발생하여 재식립 시 피질골 통과를 위해 pre-drilling 이나 수직력의 증가를 요하게 된다. 또한 recycled screw 의 생물학적 반응이 unused screw 와 비교하여 동일하다고 할 수는 없다. 따라서 교정용 미니-스크류를 recycling 하여 재사용하는 것은 생역학적으로 바람직하지 않다고 할 수 있다.

Key words : 교정용 미니-스크류, recycling, 표면 특성, 기계적 특성, 생물학적 반응.