Original Article

Biomechanical characteristics and reinsertion guidelines for retrieved orthodontic miniscrews

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ABSTRACT

Objectives: To analyze morphological variations of retrieved orthodontic miniscrews and to evaluate the mechanical properties that may adversely affect relocation of miniscrews.

Materials and Methods: Retrieved miniscrews were classified with scanning electron microscopy according to the degree of morphological deformation of the tip. To evaluate the differences in mechanical characteristics during reinsertion, changes in insertion torque, insertion time and differences in successful insertion load were compared between unused controls and retrieved miniscrews. In addition, surface composition analysis of retrieved miniscrews was performed using energy-dispersive x-ray spectroscopy.

Results: Significant tip deformation was evident in the majority (>84.5%) of retrieved miniscrews. Initial conditions such as insertion site or duration of insertion were not associated with the presence of tip deformation. Insertion load for successful bone penetration increased in proportion to the degree of tip deformation; however, serial changes in insertion torque were similar to those of the controls. Deposited debris such as carbon, calcium, and phosphorus was noted on the retrieved miniscrews.

Conclusion: Miniscrews retrieved after primary insertion exhibited decreased cutting ability due to deformation of the tip structure, as well as surface contamination. (*Angle Orthod.* 2014;84:878–884.)

KEY WORDS: Temporary anchorage device; Miniscrew; Reinsertion; Relocation

INTRODUCTION

Temporary anchorage devices (TADs) such as orthodontic miniscrews are now widely accepted in contemporary orthodontics. Various insertion protocols have been reported according to the insertion site or the design of the device, but in general, most miniscrews are inserted by either the self-tapping or the self-drilling method.[1]

Clinically, the preferred anatomical location for miniscrew insertion is an interdental space in a molar or premolar region.[2–4] Although the insertion protocol for miniscrews is relatively simple, relocation of a screw is sometimes required at various times during treatment. During the insertion process, immediate relocation may be needed because of anatomical limitations such as proximity of roots, blood vessels, and nerves; lack of primary stability; or pain.[5–7] During treatment, miniscrews inserted between the tooth roots may interfere with the path of tooth movement, since the interdental space is limited. For example, the tooth root may come into contact with the miniscrew during the course of distalization or molar intrusion, hindering further tooth movement and calling for timely reloca-

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tion.[8] In addition, since root proximity significantly increases the risk of miniscrew mobility/failure, secondary failure may occur during the course of tooth movement, eventually leading to a need for relocation.[9] Sometimes miniscrews are relocated even after active treatment to apply force for active retention in cases such as open bite malocclusion treated by molar intrusion.[10]

Miniscrews retrieved after successful use have been reported to show surface alterations.[11] However, the biomechanical characteristics of a miniscrew that has penetrated bone once, as well as the options for or limitations of miniscrew reinsertion, have not been discussed in the orthodontic literature. Therefore, the objective of this study was to analyze morphological variations of retrieved miniscrews and to evaluate the mechanical properties that may limit the relocation process.

MATERIALS AND METHODS

Eighty-four retrieved orthodontic miniscrews were collected after successful use in 54 adult orthodontic patients (16 men and 38 women) at the Department of Orthodontics, Gangnam Severance Hospital, Yonsei University, Seoul, Korea. The sample miniscrews were the drill-free type, with a combined cylindrical and tapered design, and were 1.6 mm in diameter and 7 mm in length (16107, Ortholution, Seoul, Korea). After retrieval by reverse rotation with the provided hand driver, the miniscrews were packaged into autoclave bags and labeled with background information such as host gender, insertion site, and dates of insertion and removal to calculate the duration of use. Eight unused miniscrews of the same type served as controls. The study was approved by the Institutional Review Board of Gangnam Severance Hospital, Yonsei University.

An artificial bone block consisting of solid rigid polyurethane foam (Sawbones, A Division of Pacific Research Laboratories Inc, Vashon, Wash) was used to test biomechanical insertion properties of the retrieved miniscrews. To reproduce cortical bone, E-glass–filled epoxy sheets were cut 1 mm thick using a milling machine (NSM-A, Nam Sun Machine Tools Co Ltd, Seoul, Korea) and attached to the solid rigid polyurethane foam block with acrylate bonding adhesive (Automix, 3M, St. Paul, Minn).[12,13]

Morphological Evaluation

Scanning electron microscopy (SEM) (Hitachi S3000N, Tokyo, Japan) of the miniscrews fixed in the same orientation was performed at 20 kV acceleration voltage and $35\times-100\times$ magnification. The retrieved miniscrews were classified according to the changes in tip morphology and the increase of the α value compared with the controls. The α value was defined as the distance between the screw tip and the point of intersection of two tangent lines of the miniscrew tip margins (Figure 1A; the length of the arrow, in microns) and was measured using ImageJ software (NIH, Bethesda, Md). Increasing α values indicated greater deformation of the tip and were compared with the α values of the control miniscrews (Figure 1B). Group 1 was defined as retrieved miniscrews with comparable tip morphology with the unused controls with α values within the lower and upper limits of the control group in the 95% confidence interval (CI) (Figure 1C). Group 2 was defined as retrieved miniscrews with minor blunting of the tip with α values exceeding the upper limit of the control group in the 95% CI (Figure 1D). Group 3 was defined as retrieved miniscrews with severe to complete deformation of the tip (Figure 1E). The α value measurement was performed three times for each miniscrew, and the average value was used for statistical evaluation.

Torque Testing

The mechanical properties during reinsertion of retrieved miniscrews were measured using a torque tester (Biomaterials Korea Inc, Seoul, Korea) with a uniform speed of 1 rotation per minute (RPM) according to the guidelines of the American Society for Testing and Materials (ASTM) F543-02.[12,13] During insertion, the changes in insertion torque and insertion time, defined as the time needed for the miniscrew to completely perforate the cortical bone, were measured every 0.1 seconds with a computer program (QuickDataAcq, SDK Developer, London, United Kingdom). When insertion of the retrieved miniscrew was not possible at the same weight conditions, the weight was increased gradually in 100-g increments.

Analysis of Surface Composition

Energy-dispersive x-ray spectroscopy (EDS) was performed after autoclave sterilization of the retrieved miniscrews to determine the surface composition. Elemental microanalysis was performed at 600 times the original magnification using field emission SEM (JSM-6700F, JEOL, Tokyo, Japan) and EDS system software (AZtecEnergy analysis software, Oxford Instruments PLC, Oxon, United Kingdom).

Statistical Analysis

All statistical analyses were performed using SPSS 17.0 software (SPSS Inc, Chicago, Ill). Descriptive statistics were used to define the degree of tip deformation, multivariate nominal regression analysis

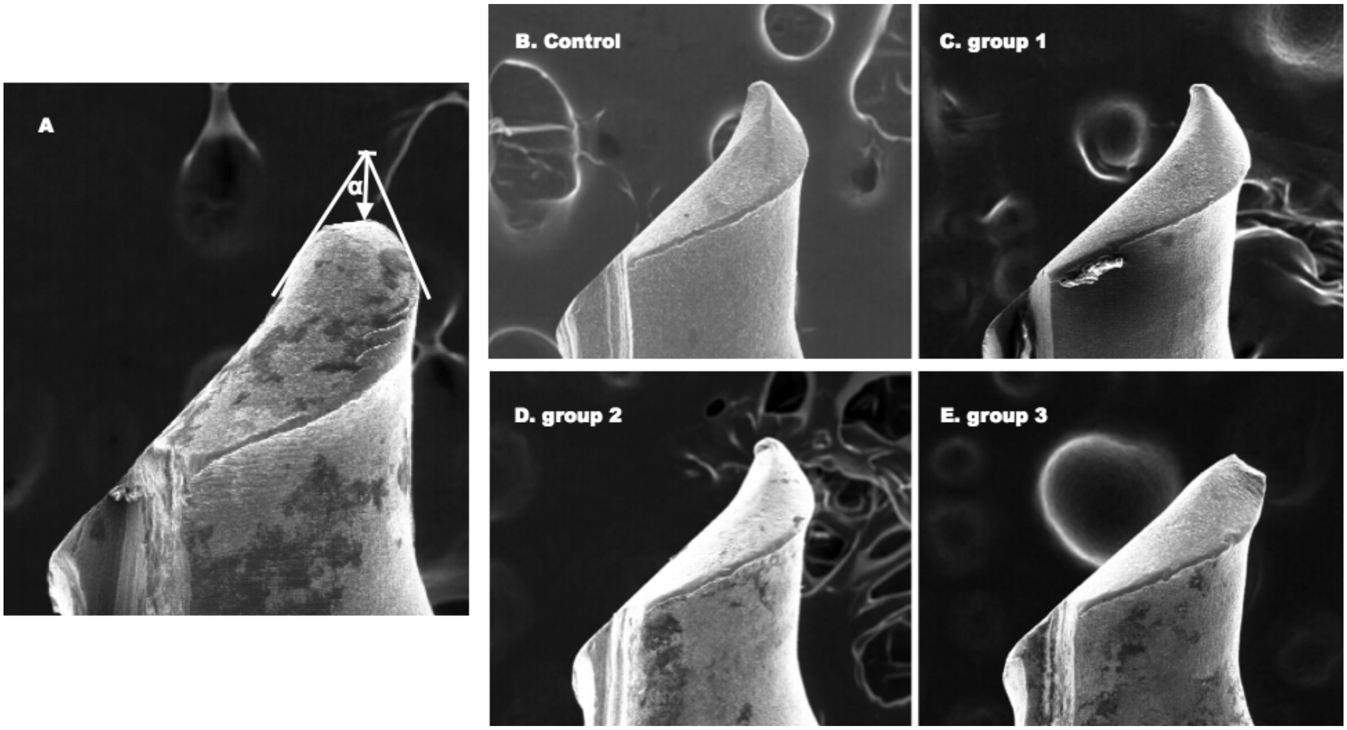

Figure 1. SEM images for morphological evaluation of the retrieved miniscrews. (A) The distance between the screw tip and the point of intersection of two tangent lines of the miniscrew tip margins was defined as α. (B) Unused controls. (C) Group 1 samples exhibited comparable tip morphology to the control. (D) Group 2 samples showed blunting of the tip. (E) Group 3 samples exhibited severe to complete deformation of the tip. The surfaces of the retrieved miniscrews were stained with attached foreign material.

was used to evaluate the clinical factors associated with tip deformation, and Fisher's exact test was used to compare the successful insertion load. All analyses in this study were performed at a significance level of $P < .05$.

RESULTS

Morphological Comparison of Control and Retrieved Miniscrews

Morphological characteristics of the retrieved miniscrews were compared with those of the unused controls with SEM. The controls had an untarnished surface with a narrow pointed tip (Figure 1B). In many of the retrieved miniscrews, the surface was stained, and in some cases, organic residues were detected throughout the miniscrew body, including the tip, thread, flute, and head (Figures 1C through E). The tip morphology varied: some miniscrews were narrow and pointed, similar to that of the controls (group 1, Figure 1C); others were mildly blunted (group 2, Figure 1D); and some were completely deformed (group 3, Figure 1E). When the retrieved miniscrews were classified according to the degree of tip deformation, group 1 comprised 15.5%; group 2, 55.9%; and group 3, 28.6% (Table 1).

The differences in host and clinical factors such as gender, initial insertion site, and insertion period of the miniscrews were not significantly associated with the presence of tip deformation (data not shown).

Mechanical Comparison of Control and Retrieved Miniscrews

For the controls, application of 400 g weight (3.92 N) perpendicular to the surface was needed to perforate the artificial bone, in addition to the default 1000-g weight of the rotational axis of the torque tester (total of 1400 g or 13.72 N). The mean insertion time was approximately 1500 seconds (Figure 2A, arrow). Compared with the relatively low and steady torque in the initial stage until the tip perforated the cortical bone, the torque dramatically increased as the body of the miniscrew was inserted (Figure 2A).

Table 1. Classification of Retrieved Miniscrews Based on the Morphological Changes of the Tip

Groups	α Value (μm)[a]		95% CI[a] of α Value		Number (%)
	Mean	SD[a]	Lower Limit	Upper Limit	
Control	38.6	5.8	24.1	53.1	8
Group 1	38.8	6.4	36	41.7	13 (15.5%)
Group 2	60.6	4.9	56.1	65.2	47 (55.9%)
Group 3	111.1	37.6	90.3	131.9	24 (28.6%)

[a] α value indicates the distance between the screw tip and the point of intersection of two tangent lines of the miniscrew tip margins; CI, confidence interval; and SD, standard deviation.

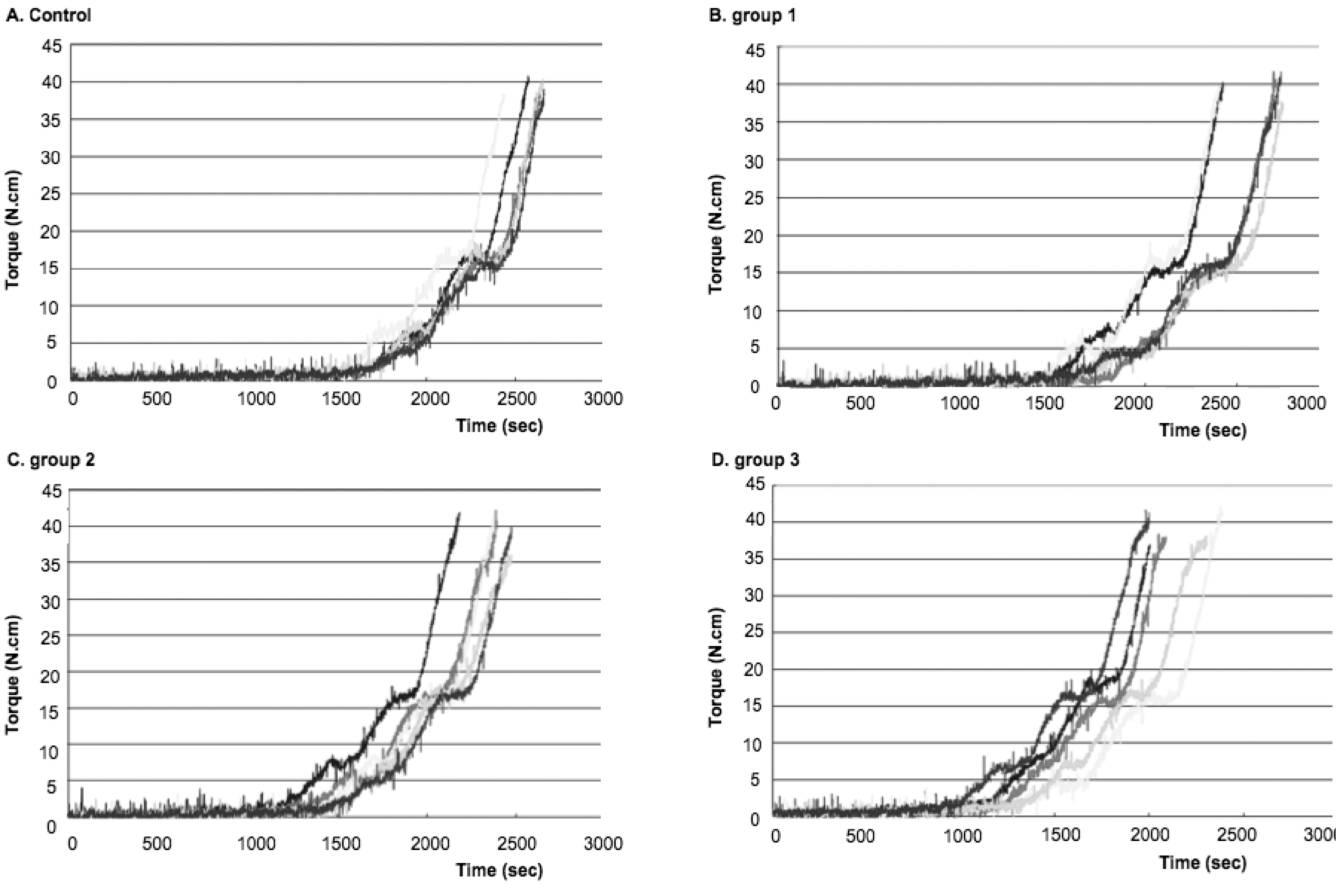

Figure 2. Graph of insertion time and torque during the insertion of five different samples in the control group (A), group 1 (B), group 2 (C), and group 3 (D). The overall changes in torque were similar among different groups; however, insertion time (arrow) varied according to the loading condition.

While all control samples were successfully inserted into the bone block with a total insertion force of 1400 g, none of six retrieved miniscrews in group 1 were able to perforate the cortical bone in the same setting. When an additional 100 g of force were added (total of 1500 g or 14.70 N), five of seven samples in group 1 (71.4%) were successfully inserted into the bone block, significantly increasing the possibility of cortical bone perforation compared to the application of 1400 g ($P < .05$). Although the pattern of changes in torque was similar to that of the controls, insertion time in three of five successfully inserted miniscrews was prolonged, regardless of the greater force (Figure 2B, Table 2).

In group 2, 1500 g was insufficient for successful insertion. The addition of 100 g (total of 1600 g or 15.68 N) significantly increased the rate of successful insertion into the bone block ($P < .05$). Although the overall pattern of changes in torque was similar among the control group, group 1, and group 2, the insertion time in group 2 was slightly decreased, to approximately 1200 seconds (Figure 2C, Table 2).

In group 3, insertion failure occurred in four of five (80%) screws with a total load of 1600 g. With an additional 100 g (total of 1700 g or 16.66 N) of force, five of six (83.3%) screws were inserted into the bone block, with similar patterns of changes in torque. A

Table 2. Differences in Miniscrew Loading Conditions for Successful Insertion

Groups	Load (N)	Total Number	Inserted (%)	Failed to Insert (%)	Sig.[a]
Control	13.72 N (1,400 g)	5	5 (100%)	0	
Group 1	13.72 N (1,400 g)	6	0	6 (100%)	*
	14.70 N (1,500 g)	7	5 (71.4%)	2 (28.6%)	
Group 2	14.70 N (1,500 g)	3	0	3 (100%)	*
	15.68 N (1,600 g)	5	5 (100%)	0	
Group 3	15.68 N (1,600 g)	5	1 (20.0%)	4 (80.0%)	NS
	16.66 N (1,700 g)	6	5 (83.3%)	1 (16.7%)	

[a] NS indicates not significant. * $P < .05$.

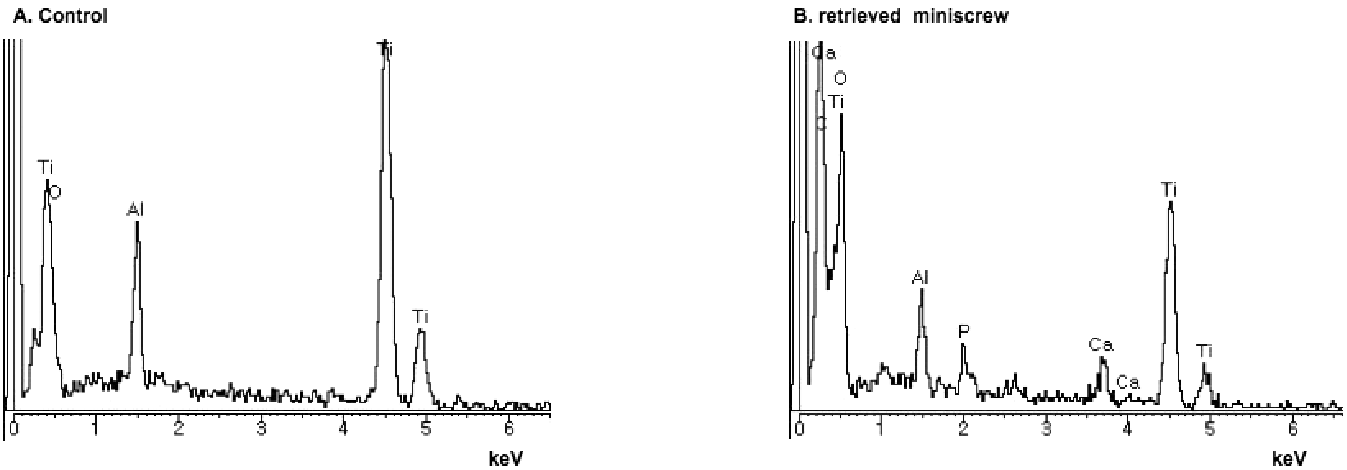

Figure 3. Elemental analysis of the miniscrew surface. (A) Titanium (Ti), oxygen (O), and aluminum (Al) were evident on the control miniscrew surface. (B) Foreign elements such as carbon (C), calcium (Ca), and phosphorus (P) were additionally evident on the retrieved miniscrew surface.

force of 1700 g tended to increase the possibility of successful insertion compared to 1600 g, but this was not statistically significant. The insertion time was decreased to approximately 1000 seconds when 1700 g of force were applied (Figure 2D, Table 2).

Elemental Microanalysis of Retrieved Miniscrews

In the control group, titanium (Ti), oxygen (O), and aluminum (Al) were the only elements detected on the miniscrew surface (Figure 3A). In the retrieved miniscrews, foreign elements such as carbon (C), calcium (Ca), and phosphorus (P) were also detected on the surface (Figure 3B).

DISCUSSION

The main role of TADs such as the orthodontic miniscrew is to provide anchorage for tooth movement or dentofacial orthopedics; thus, stability of a TAD is crucial.[14] If primary stability is not attained during insertion, many practitioners will consider removal and immediate relocation of a miniscrew to an adjacent site. Even if stability is not an issue, miniscrew relocation is sometimes recommended to achieve a precise biomechanical force configuration or to prevent root contact during treatment.[8] This study investigated comparative morphological and mechanical characteristics of retrieved and unused miniscrews and found that most of the retrieved miniscrews exhibited varying degrees of notable tip deformation. This tip deformation may interfere with the efficiency of self-drilling, particularly penetration of the cortical bone.

The main component of miniscrews is titanium, a material that is sufficiently strong and biocompatibile. Retrieved self-drilling miniscrews reportedly show surface alterations due to contact with biologic fluids but do not show bulk structure alterations.[11] Similarly, analysis of the surface composition of retrieved miniscrews in our study also indicated foreign elements, such as carbon (C), calcium (Ca), and phosphorus (P). Although the tip morphology of the retrieved miniscrews was not evaluated in previous studies, changes in the tip configuration were expected in the miniscrews examined in our study because the screws were self-drilling types with sharp cutting tips designed to effectively converge the vertical insertion force to penetrate the soft and hard tissues. The majority of retrieved miniscrews showed varying degrees of tip blunting, which hindered reinsertion. Although we postulated that miniscrews inserted into denser bone, ie, mandibular bone vs maxillary bone, might show greater tip blunting, the degree of tip deformation was not associated with any of the clinical parameters related to the host, such as the initial insertion site or the gender, in our study. The degree of tip deformation may also be affected by the insertion conditions, such as applied insertion force and RPM, insertion angle, and technical proficiency or the design of the miniscrew. Therefore, the level of tip deformation after primary insertion may not be predictable in the clinical setting.

Blunting of the screw tip restricted penetration of the cortical bone layer. Experimentally, additional higher forces proportional to the degree of deformation were needed to overcome this limitation. However, excessive insertion force may hinder soft tissue healing, cause additional screw tip deformation possibly leading to screw fracture, or induce microcracks and bone damage, all of which may negatively affect miniscrew stability.[15–17] Interestingly, cortical bone insertion time decreased slightly as additional force was applied for successful penetration in groups 2 and 3. Under the experimental condition of constantly low RPM without axial wobbling, an insertion load above a certain level may affect insertion time as well as compensate for decreased cutting ability of the miniscrew. After penetration of cortical bone, control and retrieved miniscrews displayed similar mechanical properties regardless of the degree of tip blunting; this indicated that the overall body, including the threaded region, was not affected to a notable degree. However, since only one type of commercially available self-drilling miniscrew was evaluated, there is a possibility that other types of retrieved miniscrews may show differences in terms of tip deformation and changes in biomechanical properties.

With the artificial bone block and torque tester it was possible to compare mechanical characteristics such as insertion time and to track serial changes in torque. The pounds per cubic foot of cancellous bone block used in this study was 40, which is similar to the density of molar alveolar bone in the mandible.[12] To monitor the precise changes between the retrieved and control miniscrews, the RPM setting was decreased to 1 RPM, much lower than what would be used clinically but within the recommended range for mechanical evaluation stipulated in the ASTM guidelines.[12,13]

This study was not designed to investigate the recycling of used miniscrews. However, in the clinical setting, reinsertion or immediate relocation is commonly performed, without any clinical guidelines. On the basis of our findings, biomechanically compatible pilot drilling may allow bone penetration of retrieved self-drilling miniscrews. However, additional drilling may also cause problems, such as thermal necrosis of the surrounding bone and drill-bit breakage.[17] More importantly, the retrieved miniscrews exhibited unpredictable tip deformations and surface contamination, even after autoclave sterilization, due to previous contact with bone, blood, and tissue fluids. These changes in morphology and surface composition may interfere with healing of the bone/miniscrew interface and mechanical stability, leading to secondary failure, not to mention other health-related issues such as increased risk of miniscrew fracture, infection, or immunologic responses.[11,18,19] Therefore, the reuse of retrieved miniscrews is not recommended in general, and reinsertion should be restricted only to immediate relocation following primary failure together with careful pilot drilling in a clinically aseptic setting.

CONCLUSIONS

- Miniscrews retrieved after primary insertion exhibited decreased cutting ability due to deformation of the tip structure, as well as surface contamination.
- Reuse of retrieved miniscrews is not recommended due to their biomechanical and biological shortcomings.

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