Original Article

Does the Bone Cement Affect Miniscrew Stability?

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ABSTRACT

Objective: The purpose of this study was to determine whether bone cement increased the resistance of miniscrews against pull-out and shear forces.

Materials and Method: Sixty commercially available miniscrews were placed into bovine bone samples (one each) at a 90° angle, using a custom-made orientation jig and controlling torque (30 N-cm) and rotation (20 rpm) with a rechargeable screwdriver. The miniscrews were inserted using three different methods: self-drilling, predrilling, and predrilling with bone cement application. Pull-out strengths and shear tests were performed using a universal testing machine.

Results: Nonparametric Kruskal-Wallis tests were used for comparisons between groups, and Bonferroni-adjusted Mann-Whitney *U* tests were used to detect different group(s) ($\alpha/3=0.016$). There was a statistically significant difference between the pull-out strengths of the groups ($p<0.01$). The self-drilling group had a significantly lower pull-out strength at failure than the other groups ($p<0.016$). The pullout strengths of the miniscrews placed with bone cement had a significantly higher pull-out strength than the predrilling group. In shear tests, there was no statistically significant difference among the groups.

Conclusion: This study is the first report demonstrating the effects of bone cement on stability and resistance to failure at the bone-miniscrew interface. These results show that the use of miniscrews with bone cement is a promising method that may extend the limits of force application. (*Turkish J Orthod* 2013;26:119–128)

KEY WORDS: Bone Cement, Mini screw, Pull-out, Shear

INTRODUCTION

In many cases, appropriate anchorage is very important for successful treatment results. Orthodontic miniscrews have gained much interest as skeletal anchorage units in recent years because of their simple application, minimally invasive surgery procedure, immediate loading properties, and low costs.[1–3]

However, despite these evident advantages, miniscrews are not failproof. Park and colleagues.[4] reported a miniscrew failure rate of 8.4%, and Kuroda and colleagues[5] reported a failure rate of less than 20%. Success rates for miniscrews have been reported at 80–95% in many studies.[4–6] Causes of miniscrew failure include vibration of the miniscrew driver used during the procedure, infection in surrounding tissues, lack of attached gingiva, and application of excessive force.[4,7,8] However, the main reason for miniscrew failure is loss of bone and implant contact, which affects both primary and secondary stability phases.[9]

Thus, many attempts have been made to enhance the stability and success rate of miniscrews. These advances include modifications of size, shape, and thread design; sandblasting; acid-etching of the surfaces; and appropriate timing for the application of force. However, research continues to focus on finding ways to achieve better stability with miniscrews.[10–16]

Screws similar to those used in orthodontics are also used in orthopedics to provide anchorages for internal stabilization in spinal surgery. However,

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pedicle screw instrumentation in a severely osteoporotic spine remains a challenge for orthopedic surgeons. To overcome this problem and improve the screw holding power, efforts have focused primarily on the pull-out of screws augmented with polymethylmethacrylate (PMMA). Several laboratory studies on cadaver spines have demonstrated that pedicle screw fixation augmented with bone cement (PMMA) results in a significantly increased axial pull-out force and transverse bending stiffness.[17–20] Thus, inspired from findings on the benefits of bone cement in the field of orthopedics, we sought to determine whether use of PMMA in orthodontics increases the primary stability of miniscrews compared with conventional application methods.

This study is designed to investigate whether bone cement increased the resistance of miniscrews against pull-out and shear forces and to demonstrate the effects of bone cement on the stability and resistance to failure at the bone-miniscrew interface.

MATERIALS AND METHOD

The sample group consisted of 60 bone pieces obtained from bovine ribs of the same animal. Suitable bone pieces were chosen according to the measurements done on the computed tomography images. Inclusion criteria for cortical bone thickness was 1.9 ± 0.7 mm. All pieces were embedded in acrylic resin on the same day (the day after the animal was killed) and curing was performed chemically by polymerization energy (Fig. 1). The samples were wrapped with damp cloths, put into locked plastic bags, and preserved in the fridge at –5°C until the research was finished; according to Evans and colleagues,[21] this waiting procedure does not affect bone elasticity.

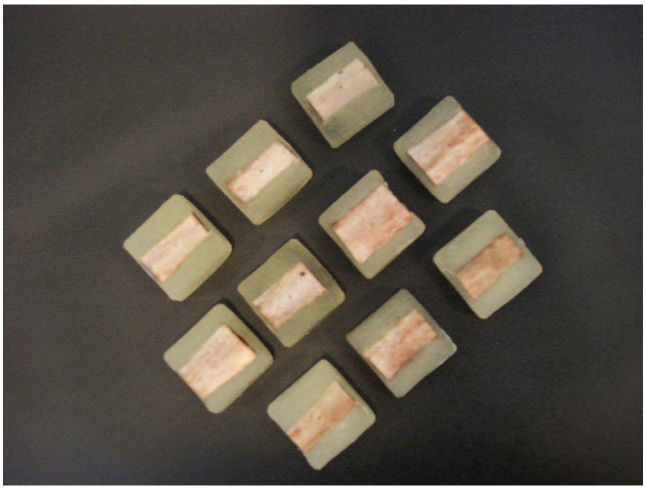


Figure 1. Bone samples used in the study.

Figure 2. Tested miniscrew: 1.6 × 7 mm (Turkuaz, TasarımMed, Istanbul, Turkey).

Sixty commercially available miniscrews (1.6 × 7 mm, Turkuaz, TasarımMed, Istanbul, Turkey; Fig. 2) were placed as received in bovine bone samples (one each) at a 90° angle using a custom-made orientation jig and controlling torque (30 N-cm) and rotation (20 rpm) with a rechargeable screwdriver (Orthonia, Jeil Medical Corp, Seoul, Korea; Fig. 3a and b). The following three methods were used (20 samples each):

- Self-drilling (Fig. 4)
- Predrilling
- Predrilling with bone cement application

In all three methods, when the torque value exceeded 30 N-cm during insertion, the screwdriver automatically stopped. In all samples, the threaded part of the screws was inserted fully. All the miniscrews were autoclaved before insertion; no other cleaning procedure was used.

In the predrilling and bone-cement groups, pilot holes were prepared in the direction of the planned miniscrew insertion with a drilling machine at 600 rpm (Fig. 5). Drilling depths were configured at 5 mm with a 1.25-mm predrilling diameter.

In the bone-cement group, the cement (DePuy Endurance CMW, DePuy International Ltd, Blackpool, UK) was a 2-component system consisting of separate sterile powder and liquid components, which were mixed together at the point of use to produce the cement. The powder was a PMMA-based polymer. The liquid component was a colorless, flammable liquid with a distinctive odor

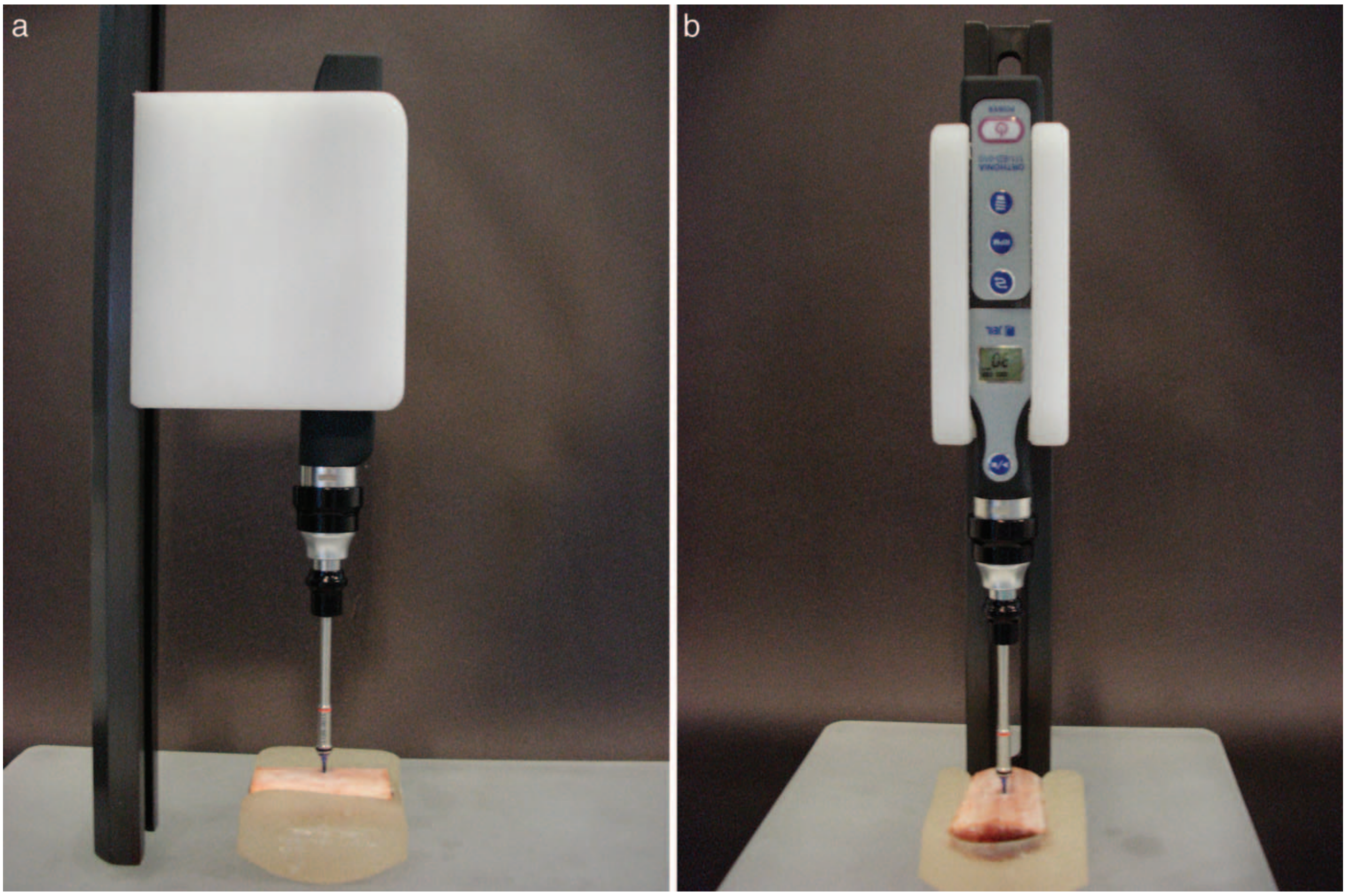


Figure 3. (a) Lateral view and (b) Frontal view of the custom-made orientation jig that holds the rechargeable screwdriver.

and consisted mainly of methylmethacrylate monomer. The bone cements were self-curing, radiopaque, and PMMA based. The standard dose of bone cement was prepared by mixing the same amount of liquid with powder. In our study, when each miniscrew was placed, the same amount of liquid and powder was mixed at the point of use of cement after a minimum of 24 hours of storage time at 23°C as recommended by the manufacturer. The cement was applied using a lentulo spiral for proper distribution in the predrilled hole until it was full (Fig. 6); a suitable viscosity of the cement was achieved when it could be handled with the lentulo spiral. All the mixing equipment with the lentulo was equilibrated to 23°C before usage. Although the manufacturer says variations in humidity affect cement handling, the cementing procedure has been done in our lab, under the same conditions as in the clinics, without any adjustment. The miniscrew was then placed in the cement.

The design test matrix consisted of six subgroups of 10 miniscrews each. Three subgroups were pull-out tests and the remaining three were shear tests. Pull-out and shear tests were performed just after the miniscrews were inserted and polymerization was completed for the cement group. Specimens were loaded at a cross-head speed of 1 mm/min using a universal testing machine (Autograph AG-IC-50kN, Shimadzu, Kyoto, Japan). To evaluate the

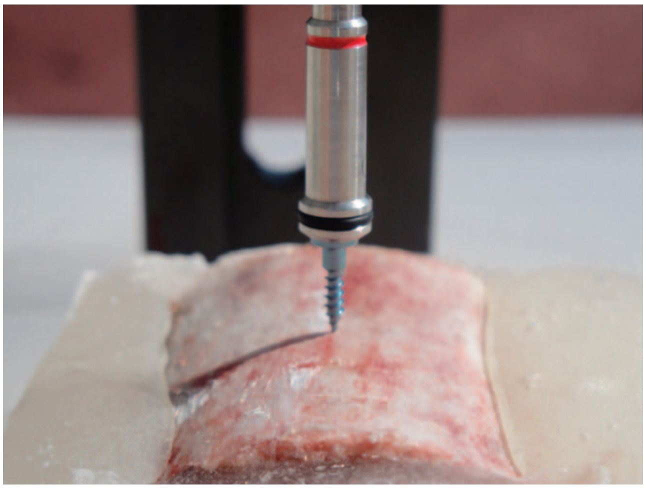


Figure 4. Insertion of self-drilling screw.

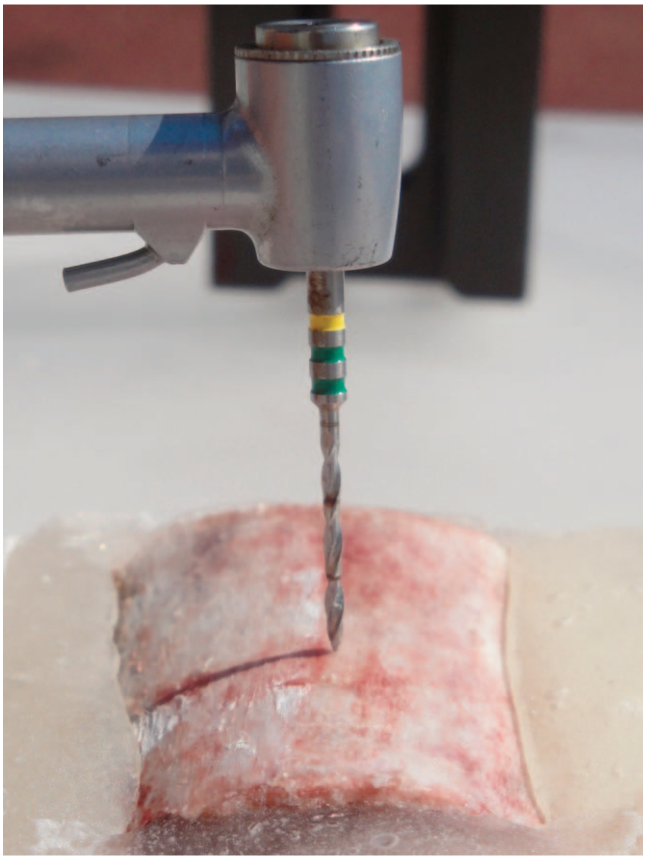


Figure 5. Pilot hole preperation.

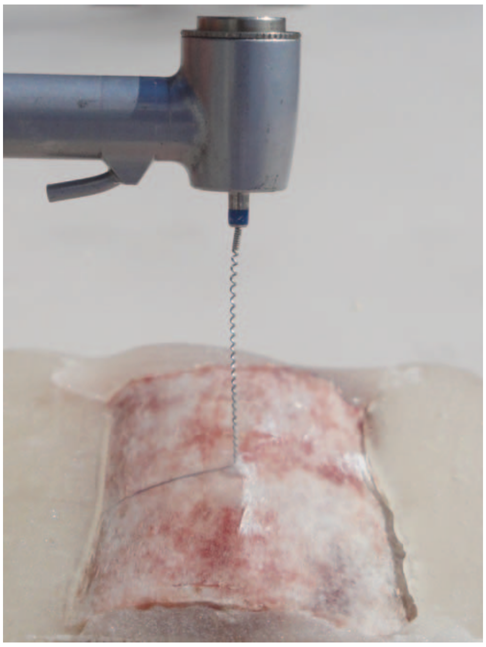


Figure 6. Application of bone cement by means of a lentulo spiral.

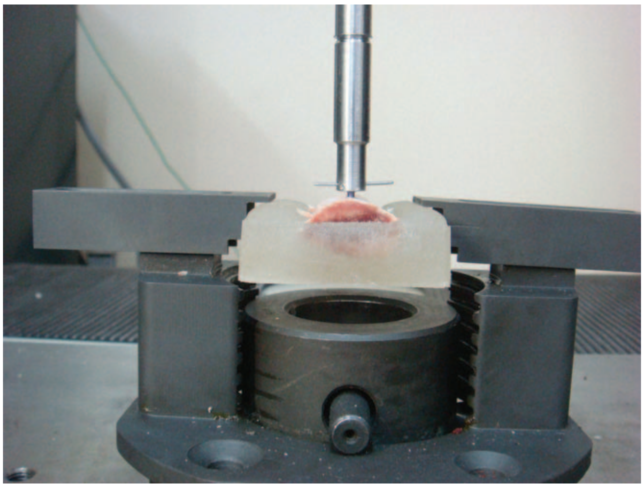


Figure 7. Custom-made attachment fabricated for evaluating pull-out strength.

pull-out strength, the bone/screw block in the acrylic base was attached to the jig via the screw by means of a 1-mm-thick reinforced metal rod passed through the hole on the head of the screw. The acrylic base was secured with 2 metal clamps (Fig. 7). It was designed to allow rotational and *x-y* freedom during

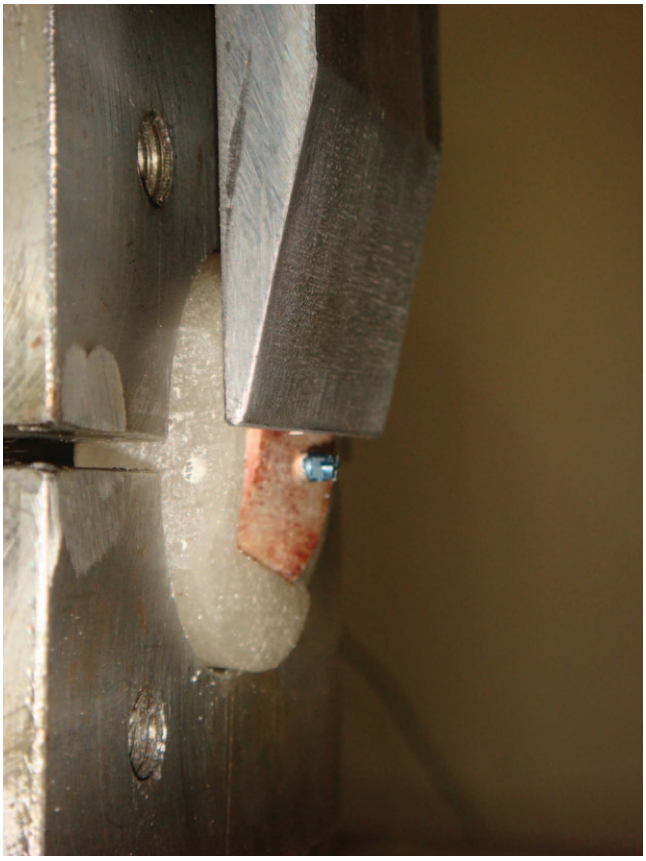
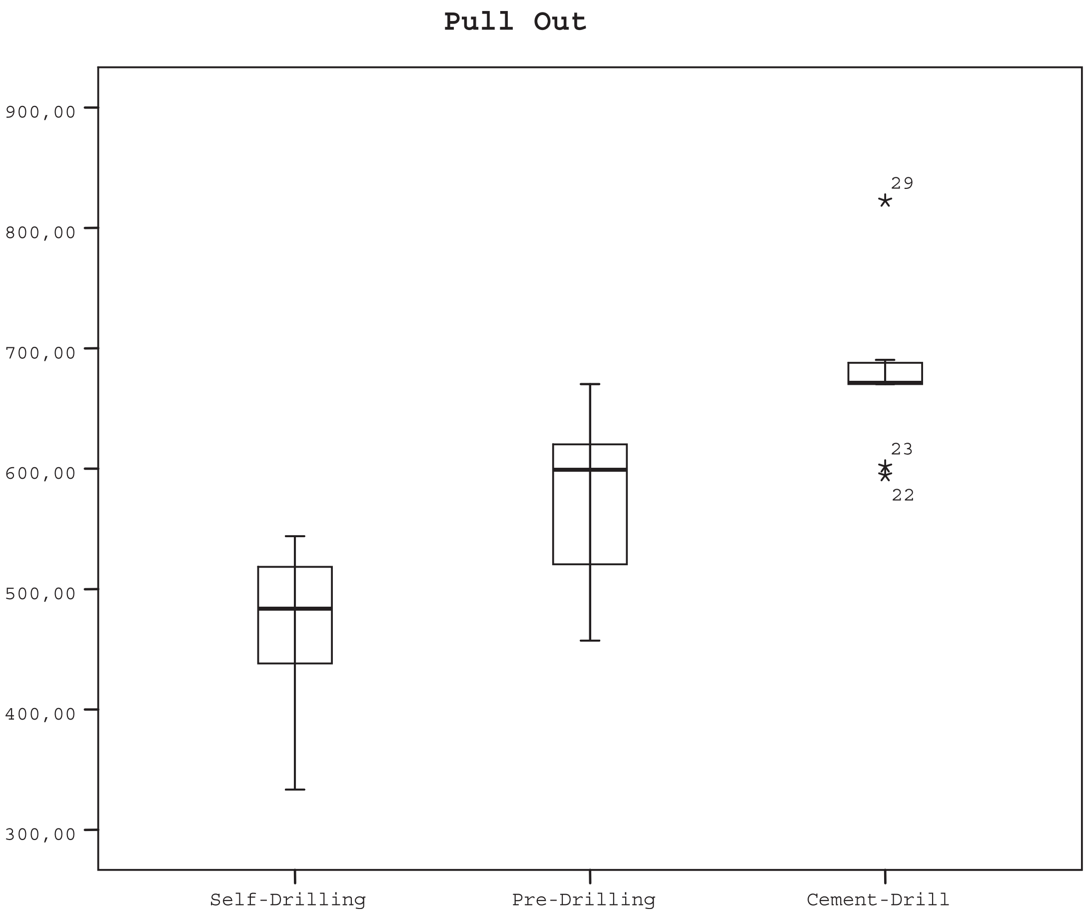


Figure 8. Shear test mechanism used for evaluation.

Table 1. Descriptive statistics of maximum force at failure.



attachment of the miniscrews to the testing machine. For the shear test, acrylic base-blocks were fixed to the testing machine by means of a special attachment to orient the line of shear force along the bone surface and perpendicular to the miniscrew (Fig. 8).

The findings of this study were evaluated using the SPSS software (version 15 for Windows, SPSS Inc, Chicago, IL, USA). The parameters were not normally distributed, so nonparametric Kruskal-Wallis tests were used for comparisons between groups and Bonferroni-adjusted Mann-Whitney *U* tests were used to detect any groups that were different ($\alpha/3=0.016$). The level of significance taken into consideration for the statistical analysis was $p < 0.01$.

RESULTS

A statistically significant difference was found between the pull-out strengths of the groups ($p<0.01$). The self-drilling group had a significantly lower pull-out strength than the other groups at failure (472.38±62.20 N: $p<0.01$) (Table 1). The pull-out strengths of the miniscrews placed with bone cement were significantly greater than those of the predrilling group (675.51±61.56 N; $p<0.01$). (Table 2) In shear tests, there was no statistically significant difference among the groups (Tables 3 and 4).

DISCUSSION

The aim of this study was to quantify the pull-out strengths and shear of screws placed using bone cement. Although direct extrapolation from *in vitro* studies should be made with caution, we sought to provide clinicians with estimates of the pull-out and shear strengths that can be expected using bone cement.

The focus of this study was to discover differences in resistance to removal between miniscrews placed by self-drilling, predrilling, and predrilling with bone-

Table 2. Comparison between application methods

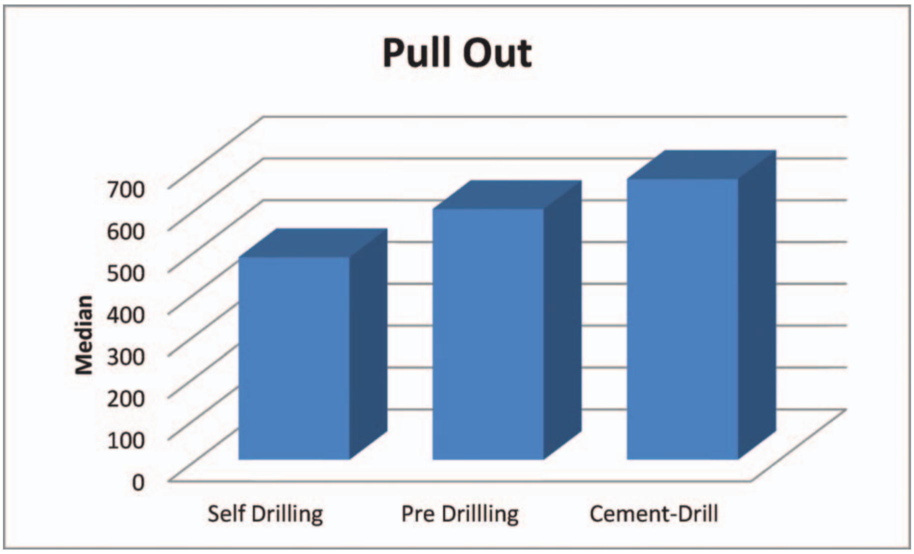


Table 3. Diagrammatic expression of pull-out strengths of the groups

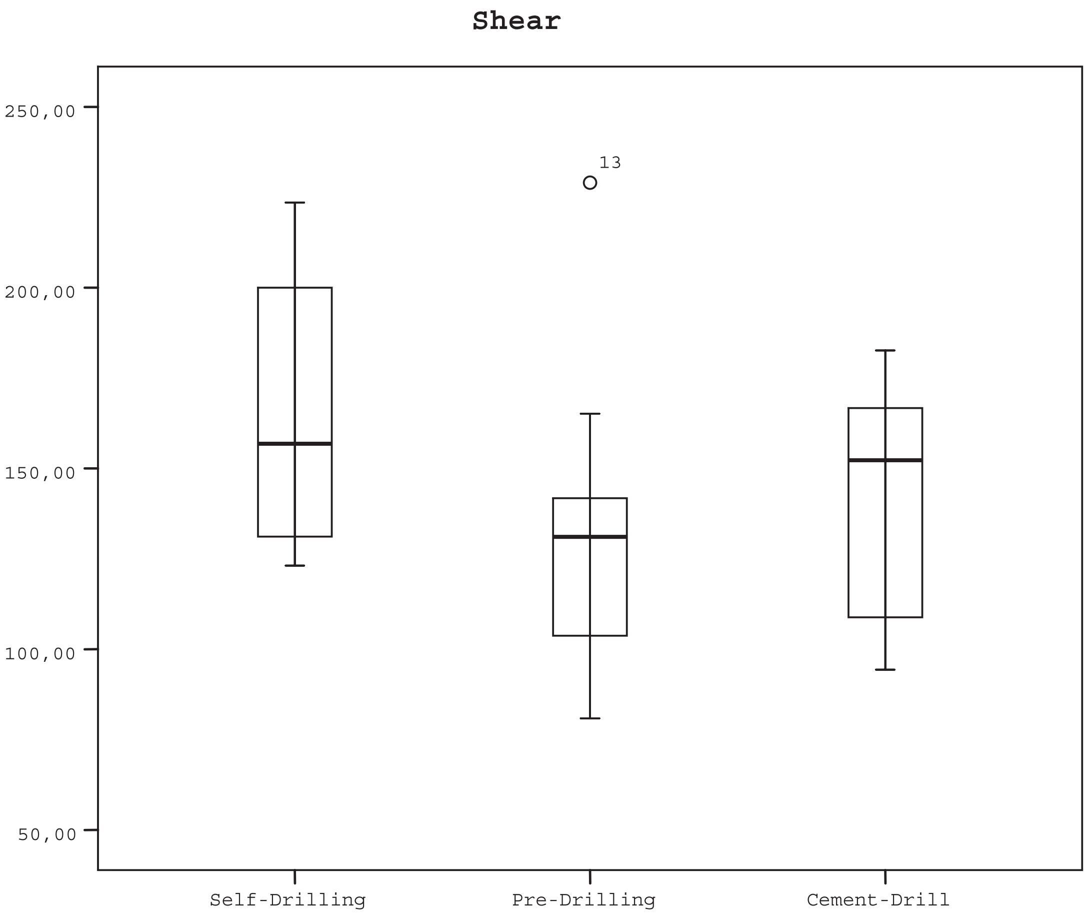
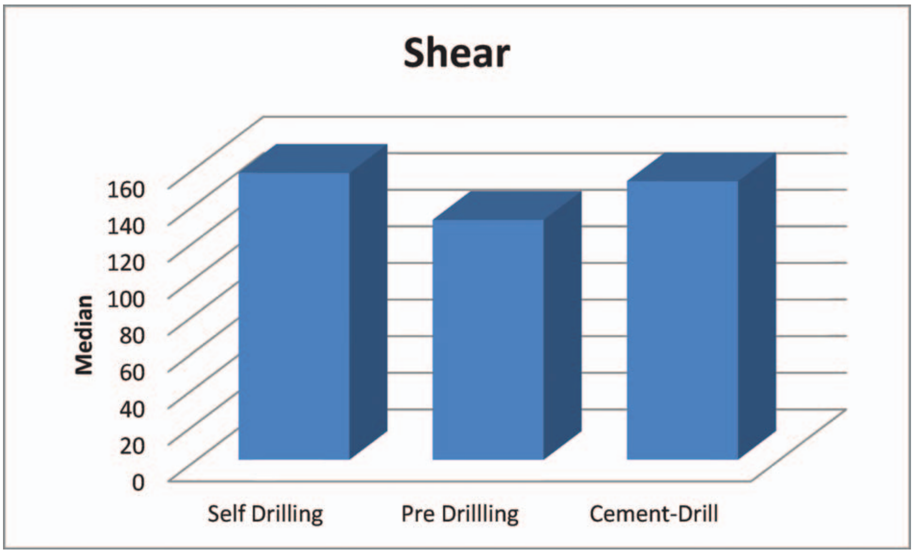


Table 4. Diagrammatic expression of shear tests of the groups



cement application and to evaluate the stability of screws with these different methods. In previous studies, to minimize variability in comparing primary stability-enhancing factors, artificial bones with mechanical properties identical to those of real bones were used. However, in the present study, to enhance stability, bone cement was used. Because of the possibility of unpredictable chemical reactions between artificial bone and bone cement, bovine bone samples were used. According to Huja and colleagues,[15] the cortical thickness of miniscrew sites in maxilla and mandible ranges between 1.3 mm and 2.5 mm. In our research we used bovine bones, which had a mean cortical thickness of 1.9 ± 0.7 mm, similar to the measurements of Huja and colleagues.[15]

Also, to prevent insertion-related variability, a custom-made mechanical insertion device with a controlled rechargeable screwdriver was used. An alternative would have been to use a hand driver, but this would cause uncontrolled lateral movement and nonuniform pressure.[22]

In orthopedics, as a result of the large diameter of screws (5.0–8.5 mm) bone cement is injected directly into the prepared pilot hole of the vertebral body before screw insertion or using cannulated screws with cement injection through the perforation.[23] However, in the present study, because the screw diameter was small (1.7 mm), bone cement was applied using a lentulo spiral for proper distribution in the predrilled hole until it was full. The diameter of the screws may affect the amount of injected cement; this may be an important factor in determining the screw holding power.

Because this was an *in vitro* study, the biological changes that occur with osseous loading could not be examined. Unlike traditional endosseous implants, which depend on a waiting period for bone healing and osseointegration, the primary stability of orthodontic miniscrews is thought to result from mechanical retention of the screw in the bone. The ability of miniscrews to be mechanically retained allows for an *in vitro* study with no need to allow for healing or biological adaptation. This study provides an indication of anchorage in the case of immediate loading after miniscrew placement. Chen and colleagues[24] suggested that titanium alloy microimplants with small diameters (1.2–1.3 mm) were strong enough for self-drilling and immediate loading in thin cortical bone areas, but to decrease the risk of breakage, a pilot hole was suggested in thicker cortical bone areas.[25]

Also, in studies of the effects of bone cements, cyanoacrylate-based β-tricalcium phosphate has been used to increase pull-out strength.[26] In this study, PMMA was assessed with regard to increasing the stability of miniscrews. In fact, bone cements have no intrinsic adhesive properties but instead, rely on close mechanical interlocking between the irregular bone surface and the miniscrew.

Regarding the condition of the miniscrew, bone, and cement trilogy after extraction, nearly 90% of the cement particles came out with the miniscrews after extraction, but some residual cement could be seen in the predrill hole, which means screw + cement showed a better interface behavior than bone + cement. Also, as some particles remained in the bone predrill hole, an *in vivo* investigation should be done to determine the healing process of the bone after removing the miniscrew, or use of different types of cements could be considered from the aspect of remaining particles.

Polymerization of PMMA is an exothermic reaction. As the completion of cement polymerization occurs in the patient, there is considerable liberation of heat into surrounding tissues. Indeed, two major problems that have been reported with the use of PMMA cement are thermal necrosis of surrounding bone due to the high heat generation during polymerization and chemical necrosis, due to unreacted monomer release.[27–29] Stanczyka and Van Rietbergenb[30] calculated that a fraction of the bone volume is exposed to temperatures of 45°C to 70°C. Because thermal necrosis is known to occur in bone tissue exposed to temperatures exceeding 50°C for more than 1 minute,[31–32] it seems unlikely that cells subjected to the conditions in his study would survive, and necrosis would be expected. Also, bone embedded in cement cannot be remodeled, and it is likely that the bone-cement interface will remain intact and capable of load carrying at least as long as no microfractures occur.

PMMA bone cements are also used with vertebroplasty, an orthopedic technique commonly performed to treat painful vertebral compression fractures. In an *in vivo* study, Urrutia and colleagues[33] mentioned that the flow of blood through the vascular channels to the vertebral body may help to dissipate heat from an exothermic reaction. The screws should be kept in a cold place before use and, after insertion, cold buffer should be applied directly to screws to avoid excessive heat during polymerization.

Available experimental data on the effects of the PMMA monomer on bone tissue demonstrate toxic effects.[34] In the literature, cytotoxicity testing of root-end filling material showed that PMMA had a comparable cytotoxic effect on fibroblast cells to mineral trioxide aggregate and could be a promising root-end filling material.[35] Further, histologic and *in vivo* studies should be performed to evaluate these issues. Xiea and colleagues[36] evaluated N-2-butyl cyanoacrylate as a bone-bonding anchorage and studied its histologic effects. They concluded that the loading capacity was sufficient for orthodontic use, but further study is needed to determine whether it can be used in clinical practice.

The maximum pull-out strengths of the self-drilling miniscrews in this study were compatible with the results of pull-out tests of varying miniscrew designs 1.5–2.0 mm in diameter and 5–7 mm in length.[37] The maximum shear-test results of the self-drilling miniscrews in this study were comparable to the results of Pickard and colleagues.[38] Differences may be related to the diameter and length of the miniscrews. The miniscrew they used was 6 mm long and 1.8 mm in diameter. Although Lee and colleagues[26] reported increased pull-out strength forces with cyanoacrylate cements, similar to our findings, they found a decrease in pull-out forces with predrilling.

Self-drilling miniscrews show greater bone damage than predrilling miniscrews in bone with a monocortical thickness of ~2 mm or greater.[31] With the self-drilling technique, if the bone is dense or the screw diameter is large and has a tapered shape, excessive placement torque can cause overcompression of the cortical bone, leading to microdamage.[39] Microdamage is a permanent deformation of the microstructure of loaded cortical bone in the form of fatigue and creep; it manifests histologically as microcracks that are discontinuities of the calcium-rich bone matrix around implants.[40,41] Considering that the bone samples used in this study had a 1.9 ± 0.7 mm compact area, the difference between the pull-out strengths of the predrilling and self-drilling groups may be explained by the bone cracks that formed due to the self-drilling method. Lee and colleagues[26] prepared a 0.9-mm hole for insertion of a 2.2-mm diameter miniscrew, whereas we used a 1.2-mm hole for insertion of a 1.6-mm diameter miniscrew, which could decrease bone damage. Increases in the pull-out tests were consistent with the orthopedic literature, but differences between methods were higher than our results. This may be related to the diameters of the pedicle screws and amounts of cement used.[38] Thus, future studies should concentrate on the anchoring ability of bone cements to prevent loss of miniscrews *in vivo*.

CONCLUSIONS

The conclusions of this *in vitro* study are as follows:

- Miniscrews placed with bone cement had a higher capacity to withstand pull-out forces than the two other groups.

- Miniscrews placed with the predrilling method had a higher capacity to withstand forces than the miniscrews placed with a self-drilling method.
- There was no statistically significant difference among the groups in the shear tests.
- Application of miniscrews with bone cement is a promising method that may extend the limits of force application for orthodontic movement.

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