Original Article

Evaluation and comparison of mechanical properties between commercially available mini-implants: An *in vitro* study

ABSTRACT

Objective: The objective of this study is to evaluate the mechanical properties of different commercial brands of mini-implants by subjecting them to loads perpendicular to their long axis.

Materials and Methods: A total of 120 mini-implants were divided into six groups (n = 20): Group 1A - 20 stainless steel (SS) mini-implants (SK Orthodontics, India), Group 1B - 20 SS mini-implants (BK Orthodontics, India), Group 1C - 20 SS mini-implants (JSV Surgicals, India), Group 2A - 20 titanium mini-implants (Koden surgical, India), Group 2B - 20 Titanium mini-implants (JSV Orthodontics, India), and Group 2C - 20 titanium mini-implants (Dentos, Korea) were used. The mini-implants were placed perpendicularly into 12 acrylic blocks and were submitted to mechanical tests using a standard universal testing machine (ACME, India. Model no. UNIT TEST-10). The different forces required to fracture mini-implants after undergoing 0.5, 1, 1.5, and 2 mm deformation was assessed.

Results: Mini-implants in Group 2C (Titanium Dentos Korea) required the greatest force to deform and fracture, whereas Group 1C (JSV Surgicals, India) had the lowest fracture force. Statistically significant differences were seen when an intragroup comparison was done. Statistically significant differences were seen in the comparison between the SS and titanium groups ($P < 0.05$). The SS group required lower forces to deform and fracture as compared to the titanium group.

Conclusions: SS mini-implants exhibited a high degree of resistance to deform and fracture, but they were inferior compared with titanium mini-implants. Titanium mini-implants required higher force values to deform and fracture.

Keywords: Deformation, mini-implants, mini-screws, stress

INTRODUCTION

Anchorage plays a paramount role in orthodontic treatment planning.[1] For years, orthodontic treatment has been limited in scope due to the range of tooth movements possible.[2] Even within the limitations imposed as a result of this, anchorage was another issue that had to be tackled. The use of headgears, transpalatal arch, and Nance palatal button to augment anchorage had its own set of problems. These severe restrictions led to the excessive use of functional appliances and orthognathic surgical procedures.[3] The introduction of

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mini-implants and miniplates so forth has brought about a paradigm shift in the field of orthodontics.[4] Many cases which need maximum anchorage for the retraction or need intrusion/extrusion of the anterior and posterior teeth can be treated now by fixed appliances well within reasonable limits with the help of mini-implants. Mini-implants have expanded treatment possibilities because of less patient compliance, thus reducing unwanted tooth movements and facilitating previously unattainable or difficult tooth movements.[5]

Miniscrew implants have several advantages such as relatively simple implantation and removal procedures, reduced need for patient cooperation, fewer side effects on teeth, and reduced costs over the conventional methods of skeletal anchorage.[6] Moreover, their small diameter allows placement into several areas of the maxilla and the mandible that were previously unavailable, such as the alveolar bone between the roots of adjacent teeth. Much of orthodontic treatment planning and biomechanics has been changed due to the innovative features of miniscrew.[7] As the use of mini-implants became more popular, there has been an amplified focus on the factors that contribute to their success. Failure rates are also reported in the literature to range from 6% to as high as 30% as per Schätzle *et al*.[8]

The fracture of mini-implant during placement or removal is one such reported complication linked with mini-implants. Human and animal studies have reported fracture rates of approximately 4%–5%, but only a few studies have reported how often mini-implants fracture in the clinical setting.[9] However, recent surveys exploring orthodontist's experience with mini-implant placement have found that nearly 10%–20% of clinicians have experienced a fracture of mini-implant during placement, surpassing even the rate of root damage reported at 4%–6%.[10]

As there is a reduction in mini-implant size, a wider range of insertion sites are available which helps to mitigate the risk of root injury. The disadvantage of the reduced size entails a decrease in a miniscrew flexural strength. As a result, the maximum force required to permanently deform and fracture mini-implants is also diminished.[11] There have been many debates in literature which have suggested that one material is better than the other, SS implants have better strength and titanium implants are more biocompatible, but concrete evidence is lacking. To fill this void in the literature, the present study is designed to assess the deformation and fracture of orthodontic mini-implant of different commercial brands by submitting them to loads perpendicularly applied along their long axis.

MATERIALS AND METHODS

The study samples comprised 120 self-drilling mini-implants (60 titanium and 60 stainless steel [SS]) (size - 1.5 × 8 mm) made by different manufacturers. Sample calculation was done using power analysis. One hundred and twenty implants were found suited for this study. They were further divided into six groups based on their material and manufacturer [Table 1]. They were then placed in 12 acrylic blocks (2 cm × 4 cm × 17 cm) with guide holes of 0.5 mm [Figure 1]. The diameter with a depth of 3 and 10 mm following requirements of the American Society of Testing and Material Standards were done. Insertion was made perpendicular to acrylic blocks, 10 micro-implants for each block. The micro-implants were manually inserted by a single operator in a clockwise direction. The heads of mini-implants were engaged with their respective

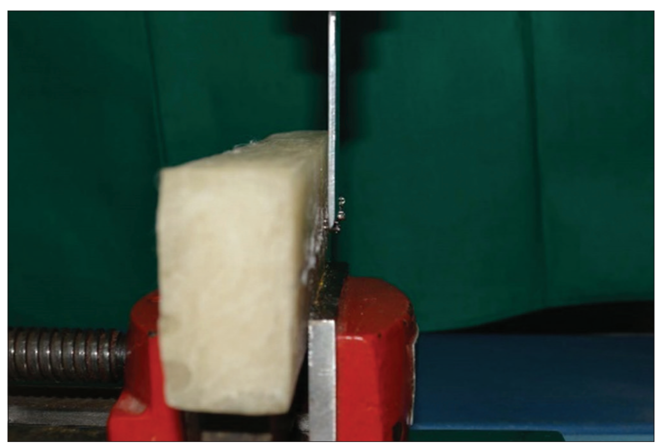

Figure 1: Acrylic blocks used in the study

Table 1: Description of mini-screws used in the study

Groups	Commercial brands	Diameter (mm)	Length (mm)	Type	Material
SS - 1A	SK surgicals	1.5	8	Tapered	Stainless steel
SS - 1B	BK surgicals	1.5	8	Tapered	Stainless steel
SS - 1C	JSV orthodontics	1.5	8	Tapered	Stainless steel
Titanium 2A	Koden	1.5	8	Tapered	Titanium
Titanium 2B	JSV orthodontics	1.5	8	Tapered	Titanium
Titanium 2C	Dentos	1.5	8	Tapered	Titanium

SS: Stainless steel

and specific manufacture provided drivers. Immediately following their insertion, all the specimens were tested by a universal Instron testing machine (computerized software-based) ACME engineers India Unittest 10, speed 0.5 mm/min. The system accuracy of the machine was ±1%. The force was applied to the screw heads to deform the screw by 0.5, 1.0, 1.5, and 2.0 mm [Figure 2]. After micro-implants had been deformed by 2 mm, the same speed of 0.5 mm/min was maintained until fracture occurred, and so this maximum value was noted.

Statistical analysis

Statistical analysis was conducted including mean and standard deviation, *P* values (intragroup and intergroup) were obtained using a one-way analysis of variance (ANOVA) along with *post hoc* Bonferroni's correction for multiple groups. The deformation and fracture point values were calculated in Newton (N) and substituted to ANOVA and *post hoc* test. Mean and SD of deformation and fracture points of six different groups were compared.

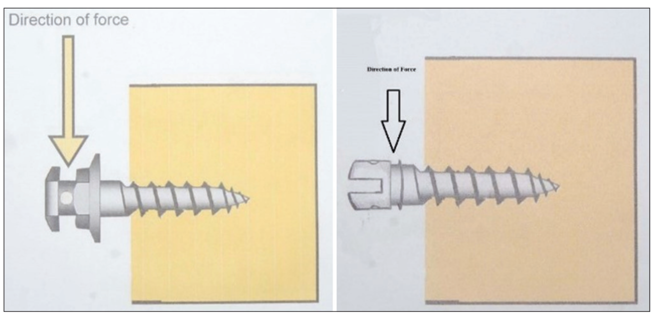

Figure 2: Direction of force application

RESULTS

The results showed deformation in all micro-implant groups. Force levels seen at various deflections are shown in Table 2 and Figure 3. The intragroup comparison revealed a statistically highly significant difference between SS Group 1A and 1C [$P < 0.001$; Table 3]. In the titanium group, a statistically significant difference was only observed between Group 2A versus Group 2C [$P < 0.001$; Table 3]. When intergroup comparison was done a statistically significant difference was seen among all the groups [$P < 0.001$; Table 4].

DISCUSSION

In recent years, the use of mini-implants to establish anchorage during orthodontic treatment has become a popular practice. These mini-implants are devices that are placed in the maxillary and mandibular bones at specified sites, thereby resisting loss of anchorage.[5] Numerous factors are responsible for the success of these mini-implants during treatment. The most popular type among orthodontists is the self-drilling type which alleviates any requirement of the preplacement osteotomy. As good as the results of these implants are, there are some drawbacks too. The most common of this being fracture of the implant during placing or removing, which have been recorded to be seen in about 4-5% cases. Breakage during use in orthodontic treatment, however, seems to be uncommon. Another common complication that orthodontists face is damage to the root. This has been seen in about 4-6% of the cases.[1]

The application of perpendicular forces on these mini-implants is common during treatment. It is therefore important to

Table 2: Forces levels at various deflections

Miniscrews group	Force (*n*) at various deflections (mm), mean±SD				
	0.5	1.0	1.5	2.0	Fracture
SS 1A (*n*=20)	46.2±4.7	57.5±5.4	68.1±5.5	76.0±5.9	102.0±9.4
SS 1B (*n*=20)	51.6±5.6	64.6±6.0	75.9±4.4	84.4±6.4	98.72±13.6
SS 1C (*n*=20)	54.5±4.3	66.9±9.0	77.2±9.5	84.5±11.1	96.28±14.3
Titanium 2A (*n*=20)	55.5±4.2	67.5±4.9	77.1±4.5	89.3±5.0	119.2±13.3
Titanium 2B (*n*=20)	58.8±3.0	71.2±5.5	81.6±5.4	91.3±5.2	129.4±13.0
Titanium 2C (*n*=20)	62.4±3.6	74.1±3.9	86.1±5.9	97.9±8.2	136.7±14.5

SD: Standard deviation, SS: Stainless steel

Table 3: Intra group comparison

P (intra group)	At 0.5 mm	At 1 mm	At 1.5 mm	At 2 mm	At fracture
SS A versus SS B	0.002**	0.005**	0.002**	0.006**	0.014*
SS A versus SS C	0.001***	0.001***	0.001***	0.006**	0.001***
SS B versus SS C	0.581 (NS)	0.999 (NS)	0.999 (NS)	0.999 (NS)	0.999 (NS)
Titanium A versus Titanium B	0.244 (NS)	0.901 (NS)	0.321 (NS)	0.999 (NS)	0.999 (NS)
Titanium A versus Titanium C	0.001***	0.012*	0.001***	0.004**	0.005**
Titanium B versus Titanium C	0.141 (NS)	0.999 (NS)	0.332 (NS)	0.066 (NS)	0.581 (NS)

*Significant, **Highly significant, ***Very highly significant. NS: Nonsignificant, SS: Stainless steel

Table 4: Inter group comparison

P (inter group)	At 0.5 mm	At 1 mm	At 1.5 mm	At 2 mm	At fracture
SS 1A versus Titanium 2A	0.001***	0.001***	0.001***	0.001***	0.001***
SS 1B versus Titanium 2B	0.001***	0.011*	0.049*	0.050*	0.033*
SS 1C versus Titanium 2C	0.001***	0.004**	0.001***	0.001***	0.001***

*Significant, **Highly significant, ***Very highly significant. SS: Stainless steel

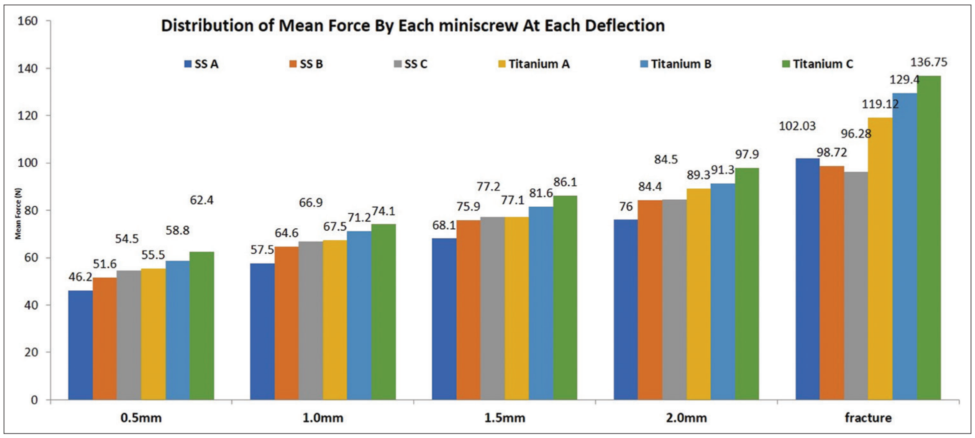

Figure 3: Mean force deflection

assess the amount of deformation seen when applying the said force. In this study, six different brands of mini-implants were chosen to assess the extent of deformation. The comparison was between SS and titanium implants. Under all levels of deflections, the implant showing greater force levels was the titanium one.[8,9] The removal torque of SS and titanium alloy implants were compared using a scanning electron microscope in a study carried out by Bollero *et al*.[12] Their results displayed that the stainless-steel implants showed fewer torque values than the titanium alloy implants. In a study contrary to this one, Wilmes *et al*.[13] determined that it was not the material but the technique of insertion, design of threads, and the length and the diameter of the implants are the factors that are responsible for the success and stability of the mini-implant.

In this study, 96–102 N was the mean fracture values for 1.5 mm diameter SS implants while those for the same diameter titanium mini-implants were 119–136 N. For a mean deflection rate of 1 mm deflection, the mean bending values were 46–54 N in the case of SS and 55–62 N for titanium implants. At a deflection of 2 mm, the values were 76–84 N and 89–97 N for the SS and titanium groups, respectively. All the values were higher than the values reported during conventional clinical applications.[14] Pan *et al*.[15] concluded that both the SS as well as the titanium implants were suitable for clinical use in orthodontic anchorage preservation.

The present study showed that there was a statistically significant difference in the fracture and bending loads of both groups, given their difference in modulus of elasticity (SS: ~193 GPa and Grade 5 titanium ~120 GPa). This could be attributed to the difference in the manufacturing protocol of each company. A study by Carano *et al*.[16] concluded that the strength of SS mini-implants was higher, thereby proving them to be more successful as compared to titanium mini-screws. This was in contradiction to the results of the present study.

Lietz *et al*.[17] carried out a study wherein it was determined that the stainless-steel implants displayed a higher resistance to moments when compared with the material of the other group. However, given the lack of SS to osseointegrate, they were speculated to have lower success rates. The correlation of the alloy and the chance of success has not yet been studied. Matheus *et al*.[1] studied different brands of titanium implants and compared their deformation and fracture when subjected to perpendicular loads along their length. They stated that the flexural strength of a mini-implant is dependent on its shape. In the present study, all the implants used were of the same shape and dimension and none of the implants were those retrieved after treatment. However, sometimes, in clinical practice, materials are retrieved, disinfected, and reused. This may affect their strength.

Six routinely used self-drilling orthodontic implants were compared by Angie Smith *et al*.[5] for their fracture torque insertion. Their study displayed a low correlation between the diameter of the implant and the fracture resistance. In situations of high-density bone where predrilling is not done, one must be careful to keep the torque of the mini implant as low as possible during insertion to avoid fracture of the implant.

The present study showed that the material of the mini implant, as well as the level of force, both were contributing factors in the fracture of the implant. Nowadays, there may not be enough evidence of differences in the mechanical properties of different orthodontic mini-screws made of SS or titanium alloys. This absence of evidence is not the evidence of absence and future studies on the topic will always be required.[18]

CONCLUSION

- Among the SS group, the highest deformation and fracture resistance values were obtained for Group 1B (BK Surgicals) and the lowest fracture resistance values were obtained for Group 1C (JSV orthodontics)
- Among the Titanium group, the highest deformation and fracture resistance values were obtained for Group 2C (Dentos) and fracture resistance values were obtained for Group 2A (Koden Surgicals)
- Titanium mini-implants required higher force values to deform and fracture
- From this study, it can be recommended that titanium implants have better mechanical properties than SS implants.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Matheus M, Nojima L, Nojima M. Assessment of flexural strength and fracture of orthodontic mini-implants. Dental Press J Orthod 2008;13:128-33.
2. Squire D, Best AM, Lindauer SJ, Laskin DM. Determining the limits of orthodontic treatment of overbite, overjet, and transverse discrepancy: A pilot study. Am J Orthod Dentofacial Orthop 2006;129:804-8.
3. Sebastian B. Mini-implants: New possibilities in interdisciplinary treatment approaches. Case Rep Dent 2014;2014:140760.
4. Cope JB. Temporary anchorage devices in orthodontics: A paradigm shift. Semin Orthod 2005;11:3-9.
5. Smith A, Hosein YK, Dunning CE, Tassi A. Fracture resistance of commonly used self-drilling orthodontic mini-implants. Angle Orthod 2015;85:26-32.
6. Papadopoulos MA, Tarawneh F. The use of miniscrew implants for temporary skeletal anchorage in orthodontics: A comprehensive review. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:e6-15.
7. Schnelle MA, Beck FM, Jaynes RM, Huja SS. A radiographic evaluation of the availability of bone for placement of miniscrews. Angle Orthod 2004;74:832-7.
8. Schätzle M, Männchen R, Zwahlen M, Lang NP. Survival and failure rates of orthodontic temporary anchorage devices: A systematic review. Clin Oral Implants Res 2009;20:1351-9.
9. Carano A, Velo S, Leone P, Siciliani G. Clinical applications of the miniscrew anchorage system. J Clin Orthod 2005;39:9-24.
10. Maino BG, Maino G, Mura P. Spider screw: Skeletal anchorage system. Prog Orthod 2005;6:70-81.
11. Fritz U, Ehmer A, Diedrich P. Clinical suitability of titanium microscrews for orthodontic anchorage-preliminary experiences. J Orofac Orthop 2004;65:410-8.
12. Bollero P, Di Fazio V, Pavoni C, Cordaro M, Cozza P, Lione R. Titanium alloy vs. stainless steel miniscrews: An *in vivo* split-mouth study. Eur Rev Med Pharmacol Sci 2018;22:2191-8.
13. Wilmes B, Ottenstreuer S, Su YY, Drescher D. Impact of implant design on primary stability of orthodontic mini-implants. J Orofac Orthop 2008;69:42-50.
14. Ren Y, Maltha JC, Kuijpers-Jagtman AM. Optimum force magnitude for orthodontic tooth movement: A systematic literature review. Angle Orthod 2003;73:86-92.
15. Pan CY, Chou ST, Tseng YC, Yang YH, Wu CY, Lan TH, *et al*. Influence of different implant materials on the primary stability of orthodontic mini-implants. Kaohsiung J Med Sci 2012;28:673-8.
16. Carano A, Lonardo P, Velo S, Incorvati C. Mechanical properties of three different commercially available miniscrews for skeletal anchorage. Prog Orthod 2005;6:82-97.
17. Lietz T, Baumgaertel S, Bowman SJ. Mini-screws-aspects of assessment and selection among different systems. In: Mini-implants in Orthodontics Innovative Anchorage Concepts. London: Quintessence 2008. p. 11-72.
18. O'Brien K, Sandler J. In the land of no evidence, is the salesman king? Am J Orthod Dentofacial Orthop 2010;138:247-9.