ORIGINAL ARTICLE

Comparison of elemental composition and morphological characteristics of orthodontic titanium mini-implants

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ABSTRACT

Objectives: To evaluate and compare the indigenous and imported titanium mini-implants for their elemental composition and morphological characteristics. **Materials and Methods:** Five indigenous titanium mini-implants of (SK Surgical, Pune, Maharashtra, India) and five imported titanium mini-implant samples (IMTEC Corp., Ardmore, OK, USA) having a length of 8 mm each was compared. Elemental analysis was done by energy dispersive spectroscopy. Morphological characteristics such as the external diameter, internal diameter, thread interval or pitch, cutting edge of the threads, the shape of the screw and length were evaluated by scanning electron microscopy. Data were analyzed by one-way ANOVA to evaluate the differences in samples of the same group, and Student's *t*-test was used to compare the morphological characteristics between the two groups. **Results:** The elemental analysis showed that the indigenous mini-implants correspond to alpha-phase titanium alloy compared to imported mini-implants which correspond to alpha + beta phase titanium alloy. Statistical tests showed that the imported mini-implants were tapered compared to indigenous mini-implants which were straight or cylindrical in shape. There was a statistically significant difference in other morphological characteristics of mini-implants between the two groups as well. **Conclusion:** Indigenous mini-implants tested were made of titanium alloy (Ti-4Al) and imported mini-implants were made of titanium alloy (Ti-6Al-4V). Significant mean differences were found in the morphological characteristics amongst the indigenous titanium mini-implants ($F > 2.49$).

Key words: Energy dispersive spectroscopy, mini-implants, scanning electron microscopy, titanium

Introduction

Anchorage has long been a challenge in orthodontics. Adequate anchorage is seen to become more difficult particularly when posterior teeth are missing. Therefore, conventional titanium implants have emerged as an alternative to traditional orthodontic anchorage. Kanomi proposed the use of titanium mini-implants for use in the orthodontic anchorage.[1] Later, these have been known as temporary anchorage devices (TADs) and have become increasingly popular.

A TAD is a device that is temporarily fixed to the bone for the purpose of enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for reactive unit altogether, and which is subsequently removed after use. The TADs are threaded and hence can be self-drilling or self-tapping. The currently available TADs can be classified as either biocompatible or biological in nature. Both groups can be sub-classified based on

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the manner in which they are attached to bone, either biochemical (osseointegrated) or mechanical (cortically stabilized).[2]

"TAD" is nonspecific; since all supplementary anchorage devices are temporary, and bone anchorage is not clearly denoted. Since the distinguishing feature common to all of these devices is that they provide anchorage through either a mechanical interlocking or biochemical integration with bone, we suggest that they are best referred to as orthodontic bone anchorage devices. Ever since its emergence, a number of implants have emerged, both imported as well as indigenous. Most of the currently available mini-implants are titanium or titanium alloy and are manufactured with a smooth machined surface that is not designed to osseointegrate.[3]

The explosive development of TADs presents a professional dilemma for orthodontists. Although a large body of evidence supports osseointegrated mini-implant anchorage, most mini-implants are not designed for osseous integration and were marketed with little or no fundamental scientific verification.[4] A more fundamental factor of failure in mini-implants is thought to be the displacement caused by the problems of the interface between the mini-implant and bone tissue. This is in turn related to the quality and quantity of bone at the implantation site, screw design including diameter, screw length and pitch design, and screw material.[5]

Although the mini-implants provide a viable alternative to conventional anchorage; however, the limiting factor for its widespread use is its cost. The indigenous implants being more economical provide a viable alternative. No studies are available in the literature to the best of our knowledge wherein the elemental composition and morphological characteristics of the varied implants, indigenous and imported are compared. Thus, the need for this study was felt to ascertain whether the indigenous mini-implants provide comparable elemental and morphological characteristics with their imported counterparts, hence providing a more economical alternative.

Objectives

1. To evaluate the chemical composition and to detect the presence of surface contaminants of indigenous and imported titanium mini-implants by using energy dispersive spectroscopy (EDS)
2. To compare the surface characteristics and the structural design, which include the external diameter, internal diameter; thread interval or pitch, cutting edge of the thread, shape, and length of indigenous and imported titanium mini-implants by using scanning electron microscopy (SEM).

Materials and Methods

Two brands of titanium mini-implants were selected for the study [Figure 1]; five indigenous titanium mini-implants (SK Surgical, Pune, Maharashtra, India) with diameter of 1.3 mm and length of 8 mm and five imported titanium mini-implants (IMTEC Corp, Ardmore, OK, USA) with diameter of 1.8 mm and length of 8 mm.

To Evaluate Chemical Composition of Indigenous and Imported Mini-implants

Chemical analysis of the samples was done by EDS to verify the gross composition of the materials. Chemical analysis was conducted on five areas per sample. An EDS X-ray was coupled to the SEM (JSM 840). In EDS equipment, the elemental composition evaluated was derived from analysis of the characteristic X-ray emission caused by excitation of atoms in the dental implants by impinging electrons. The EDS equipment has a high energy and penetrates relatively deep into the samples. The compositional information is therefore, averaged over a depth of 1 μm.

The scanned areas were assessed for any surface contaminants which could be present as a result of the milling procedure. The content of the surface contaminants were also determined by EDS.

To Compare Physical Characteristics of Indigenous and Imported Titanium Mini-implants

Surface morphology of the orthodontic mini-implants was examined with the aid of (SEM-JSM 840, Indian Institute of Sciences, Bengaluru, Karnataka, India). With accelerating voltage of 20 kV for each material, five imported titanium mini-implants samples, and five indigenous

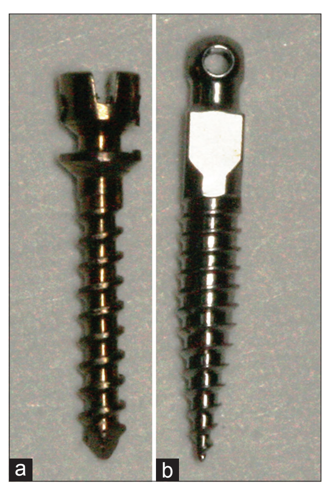

Figure 1: The two titanium mini-implants used in this study: (a) Indigenous and (b) imported

titanium mini-implants were evaluated. The surfaces of the mini-implants were scanned at different sites and photographed at a resolution of 512 × 512 pixels. Five representative photomicrographs were taken from each sample group. The data resolution normal to the image plane was to be adjusted to the best, under given scan conditions. For display purposes, the images were passed through a low-pass filter to remove spurious noise.[6]

With the help of SigmaScan Image Analyzer software (SYSTAT Software Inc, San Jose, California) morphological characteristics such as the external diameter, internal diameter, thread interval or pitch, cutting edge of the threads, the shape of the mini-implants, and length were measured from SEM images [Figure 2]. The measurements were re-measured by another examiner randomly after a week's interval to evaluate for the accuracy of the method. All the measurements were performed twice to reduce intra-examiner errors.

Statistical Analysis

Karl Pearson's correlation coefficient was utilized to analyze the constancy in external and internal diameters of two groups of titanium mini-implants. One-way ANOVA was used to analyze the differences in the samples of the same group. Student's *t*-test was used to compare the morphological characteristics between two groups of titanium mini-implants.

Results

Elemental Compositional Analysis

EDS surface analysis showed that indigenous mini-implants were composed of titanium and aluminum which correspond to alpha phase of titanium alloy. Imported mini-implants were made up of titanium, aluminum, vanadium, and trace amounts of silicon which correspond to alpha + beta (Grade 5) phase of titanium alloy [Figure 3 and Table 1].

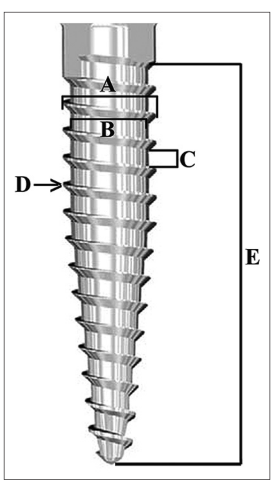

Figure 2: Parts of mini-implant evaluated: (A) External diameter, (B) internal diameter, (C) pitch, (D) cutting edge of the thread and (E) length

Surface Contaminants

On EDS analysis, iron and calcium were detected as surface contaminants in imported titanium mini-implants and silicon and calcium in indigenous mini-implants.

Surface Characterization

The SEM images at × 1000 magnification showed the surface of imported mini-implants was smoother with few streaks whereas that of indigenous mini-implants was rough with more streaks [Figure 4].

Morphological Characteristics

External and internal diameter

Correlation of external and internal diameters of the indigenous mini-implants to the total number of flutes was positive ($r = +0.4251$ and $r = +0.4081$, respectively). This suggests that the external and internal diameters of these screws were constant, and implied that as the number of flutes increased, the external diameter also remains constant from the top to the bottom of the mini-implants exhibiting a near straight or cylindrical shape. However, for imported mini-implants the correlation was negative ($r = -0.9033$ and $r = -0.8715$ respectively), indicating that the external and internal diameters were not constant which implied that when the number of flutes increased, the diameters decreased from top to bottom of the mini-implants exhibiting a tapered shape. It would be noteworthy to mention at this junction that, while the imported mini-implants had a consistent number of flutes ($n = 12$), the indigenous mini-implants had a varying number of flutes ranging from 8 to 10 for the same length of mini-implants (8 mm).

There was statistically significant mean difference ($F > 2.49$) among the samples of indigenous mini-implants, indicating great variations in the external and internal diameters whereas there was no statistically significant mean difference among the samples of imported mini-implants ($F < 2.49$), indicating no variation in their external and internal diameters.

Table 1: Elemental composition of indigenous and imported titanium mini-implants

Mini-implant	Diameter (mm)	Composition (weight %)			
		Titanium	Aluminum	Vanadium	Silicon
Indigenous	1.3	95.81±0.49	4.19±0.49	-	-
Imported	1.8	91.00±1.64	4.82±0.76	3.92±1.20	0.26±0.23

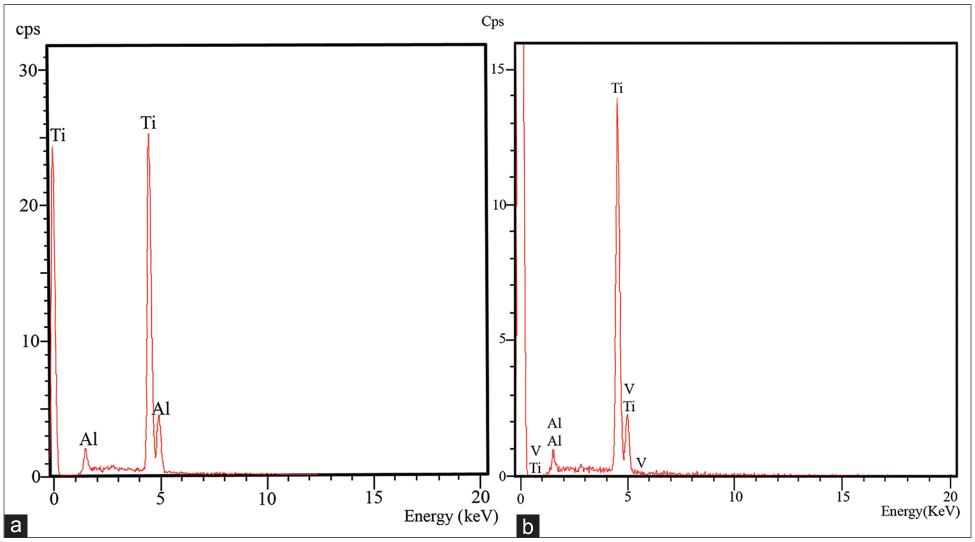

Figure 3: The graph showing elemental composition of (a) indigenous and (b) imported titanium mini-implants by using energy dispersive spectroscopy

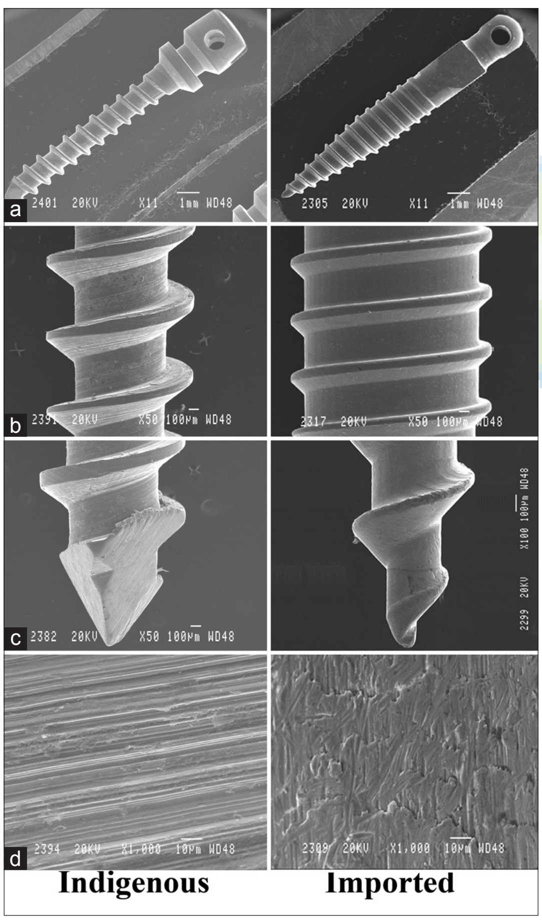

Figure 4: Scanning electron microscopy magnifications of indigenous and imported. Titanium mini-implants: (a) Mini-implant morphology (×11), (b) cutting edge of the thread (×50), (c) mini-implant tip (×100), (d) surface characterization (×1000)

When samples of indigenous and imported mini-implants were compared for the external and internal diameters, there was a statistically significant difference between the two groups ($t > 2.306$, $P < 0.05$) [Table 2].

Pitch and cutting edge of the thread

There was statistically significant mean difference ($F > 2.49$) among the samples of indigenous mini-implants suggesting great variations in the pitch and cutting edge of the thread; however, there was no statistically significant difference ($F < 2.49$) between the samples of imported mini-implants indicating no variation.

On comparison of indigenous and imported mini-implants for the pitch and cutting edge of the thread, a statistically significant mean difference between the two groups was found ($t > 2.306$, $P < 0.05$) [Table 2].

Length

The length of the mini-implants for all the samples as per the manufacturer's product description was 8 mm. In this study, the average length for imported mini-implants was 8.11 ± 0.021 mm and for indigenous mini-implants was 8.32 ± 0.35 mm [Table 2].

Discussion

Currently available implant systems are made of pure titanium (CP-Ti) or titanium alloy Ti-6Al-4V. Titanium and its alloys provide strength, rigidity, and ductility similar to those of other dental alloys. Titanium and its alloys give greater resistance to corrosion in saline and acidic environments. Even though titanium alloys are exceptionally corrosion-resistant because of the stability of the TiO_2 oxide layer, they are not inert to corrosive attack.

Table 2: Design characteristics of indigenous and imported titanium mini-implants

Design		Indigenous	Imported
External diameter-D2 (mm)	Mean (SD)	1.4179±0.0112	1.6160±0.0159
	r	+0.4251	−0.9033
	F	3.411	0.0241
	t (*P*)	20.39 (0.000017)	
Internal diameter-D1 (mm)	Mean (SD)	0.9989±0.0197	1.2837±0.0547
	r	+0.4081	−0.8715
	F	4.6262	0.2029
	t (*P*)	9.79 (0.00031)	
Conicity (%)		0.62	14.5
Pitch (mm)	Mean (SD)	0.3814±0.0224	0.3028±0.0083
	F	186.734	2.1749
	t (*P*)	6.59 (0.0014)	
Cutting edge of the thread (mm)	Mean (SD)	0.1255±0.0145	0.0772±0.0052
	F	13.6551	0.6738
	t (*P*)	6.27 (0.0017)	
Length (mm)	8	8.32±0.35	8.11±0.021

Correlation between the external diameters and the total number of flutes (*r*). Conicity (2-8 mm) %=(D2−D1/6×100). Values <1% were considered as cylindric shaped mini-implants. One-way ANOVA, $F>2.49$ is considered as significant. Student's *t*-test, $t>2.306$ ($P<0.05$) is considered as significant. SD: Standard deviation

When the stable oxide layer is broken down or removed and is unable to reform on parts of the surface, titanium can be as corrosive as many other base metals.[7] According to Yokoyama *et al*. titanium in a biological environment absorbs hydrogen, and this may be the reason for delayed fracture of a titanium implant.[8]

In this study, based on the EDS results, indigenous titanium mini-implants may be classified as alpha-phase titanium alloy and imported titanium mini-implants are classified as alpha-beta phase titanium alloy.

An alpha titanium alloy is composed of commercially pure titanium with alpha stabilizing elements added such as aluminum, nitrogen, and oxygen. Aluminum, when added to titanium, is a main alpha phase stabilizer. It increases the tensile strength, creep strength, and elastic modulus.[9,10] Hence, these mini-implants could prove brittle over a period due to the formation of titanium hydride in the presence of moisture, and this may be the reason for delayed fracture of the titanium implant.

EDS analysis in this study showed that imported mini-implants are composed of Ti-6Al-4V (Grade 5), in accordance with manufacturer's description.[11,12] Alpha-beta alloys have compositions of a mixture of alpha and beta phases and may contain 10–50% beta phase at room temperature one of the most successful alpha-beta alloys is Ti-6Al-4V, which has an excellent combination of strength, toughness, and corrosion resistance. It exhibits good mechanical and excellent tissue compatibility properties which make it suitable for biomedical applications. The presence of silicon (0.05–1%) in imported mini-implants is added to increase the strength, creep resistance of the alloy, to stabilize the highly unstable beta phase, and to refine the grains in the beta phase of the alloy.[9]

The EDS analysis showed the incorporation of some contaminants in all implant surfaces which includes iron and calcium in imported titanium mini-implants and silicon and calcium in indigenous titanium mini-implants. Most of the contaminants may have incorporated at several stages, including the fabrication process, cleaning, sterilization procedures and environment during handling and storage. Olefjord and Hansson suggested that inorganic contaminants should be avoided because these species can provoke the dissolution of the titanium. The presence of silicon, phosphorous, and calcium probably come from the finishing process in the titanium implant preparations.[13]

The SEM images at higher magnification showed the surface of imported titanium mini-implants screws to be seemingly smoother with few streaks when compared to that of indigenous titanium mini-implants which were rough with more streaks. However, the quantification of the amount of surface roughness was beyond the scope of this study. All the surfaces had a wavy morphology with striations, grooves, deposits, porosities, and voids on the surface of the implants which could be considered as the structural defects or consequence to mechanical polishing process during manufacturing.[6,14]

According to this study, the imported mini-implants are self-tapping screws with tapered body, thread-forming threads, and cock-screw shaped apex. However, the indigenous mini-implants are self-tapping screws with a cylindrical body, thread-cutting threads, and cutting flute at the apex. Thread-forming threads and cock-screw shaped apex in the imported mini-implants compresses the bone in and around the screw threads during the advancement; on the other hand, the thread-cutting threads in indigenous mini-implants have a notch cut out of the screw apex that cuts and removes the bone during screw placement.[5,11]

The tapered form of the imported mini-implants reduces the chances of root damage and wobbling effects during initial penetration; however, the cylindrical form of the indigenous mini-implants increases the same. Hence, it would necessitate the use of a pilot drill to initiate penetration into the bone.[5,11] According to Lim *et al*., the cylindrical screw requires a longer period to penetrate in the bone and also stated that drilling before insertion could decrease the insertion torque and promote healing.[15] Yano *et al*. in their study reported that the tapered screws can tolerate immediate-loading and achieve stable anchorage with a high rate of success. However, cylindrical screws can be used for orthodontic anchorage if there is a sufficient healing period.[16]

Observation from the SEM images of the imported mini-implants showed that the pitches were parallel, and the cutting edge of the threads was trapezoidal in shape, whereas for indigenous mini-implants pitches were parallel with rectangular shaped cutting edge of the threads. Trapezoidal threads maximize the cortical bone support and also make the penetration easy without predrilling.[14]

Conclusion

Indigenous titanium mini-implants are a viable economical alternative to imported titanium mini-implants provided adequate research is performed and its outcome incorporated at the manufacturer's level to standardize the mini-implant design. In addition, better composition of the titanium alloy of the mini-implants will maximize their fracture resistance and biocompatibility.

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Nil.

Conflicts of Interest

There are no conflicts of interest.

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